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Phase II Remedial Investigation Ewa Junction Fuel Drumming Facility

Fleet and Industrial Supply Center (FISC),
Pearl Harbor, Oahu, Hawaii

Volume 1 of 6
RI Report

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EXECUTIVE SUMMARY

A Phase II remedial investigation (RI) was conducted for the Ewa Junction Fuel Drumming Facility (EJFDF), Pearl Harbor, Oahu, Hawaii. The Phase II RI area includes the EJFDF and an offsite watercress farm area downgradient of the facility, near the shore of Pearl Harbor. The Phase II RI supplements a Phase I RI completed at the facility in 1996 (Ogden 1996), and provides additional data and analysis of the potential offsite impact of a motor gasoline (MOGAS) release.

In March 1971, vandals activated an EJFDF underground storage tank fuel pump, releasing approximately 315,000 gallons of MOGAS to the ground surface. At least 250,000 gallons infiltrated into the subsurface. Approximately 100,000 gallons of the infiltrated fuel were recovered from an interceptor trench and recovery wells. Free-phase MOGAS has not been observed in over 10 years; however, dissolved MOGAS constituents, such as benzene, toluene, ethylbenzene, and xylenes (BTEX), have been detected in near-surface caprock groundwater beneath the facility (30–90 feet below ground surface). The Navy's major concern has been potential offsite transport of MOGAS constituents dissolved in the caprock groundwater to the watercress farm area or Pearl Harbor. The Phase I RI concluded that MOGAS constituents are not likely to migrate beyond the site boundary at concentrations that would threaten human health or the environment, but recommended continued groundwater monitoring, including offsite groundwater sampling.

Phase II RI Sampling and Analysis Program

The primary objective of the Phase II RI was to further evaluate the potential for offsite transport of dissolved MOGAS constituents in the caprock groundwater. During the first Phase II RI sampling round (June–July 1998), existing onsite caprock groundwater monitoring wells were sampled; subsurface soil and groundwater samples were collected from new offsite borings, direct-push microwells, and monitoring wells; and offsite surface soil, surface water, and sediment samples were collected. In the second sampling round (approximately 1 year after the first round), groundwater samples were collected from the onsite monitoring wells, offsite monitoring wells, and offsite artesian wells that supply water from a deep, confined basal aquifer to the watercress fields. The groundwater samples were analyzed for total petroleum hydrocarbons (TPH), volatile organic compounds (VOCs), semivolatile organic compounds (SVOCs), lead, and other priority pollutant metals, as well as hydrogeochemical parameters indicative of hydrocarbon bioremediation.

Phase II RI Analytical Results

Phase II RI analytical results indicate that contaminants associated with the MOGAS release have remained almost completely within the site boundary, in subsurface soils and caprock groundwater near the MOGAS source. The maximum total BTEX groundwater concentration detected in 1999 was less than 600 parts per billion (ppb), much lower than the 4,200 ppb detected in the last Phase I RI sampling round (1994). In offsite groundwater, no BTEX compounds were detected except in one of the microwells, where toluene was detected at about 1 ppb. (The Safe Drinking Water Act maximum contaminant level for toluene is 1,000 ppb.) MOGAS constituents were not detected in the artesian wells, nor in surface soil, surface water, or sediment samples from the farm area.

Very low lead concentrations (well below risk-based screening criteria) were detected in offsite subsurface soils, and in monitoring well groundwater samples collected both on and off site. Higher lead levels were detected in turbid (unfiltered) groundwater samples collected from some of the offsite microwells. However, the microwell samples contained high levels of suspended solids, suggesting that the lead is associated with suspended soil particles. The spatial distribution of lead and other metals in the caprock water-bearing zone indicates that the MOGAS release is not a significant metals source. Lead was also detected in offsite surface soil, sediment, and (unfiltered)

surface water samples. The lead detected in surface water is also likely to be associated with suspended soil particles. Lead levels detected in the sediment and surface water samples are consistent with the lead levels detected in offsite surface soil. The overall distribution of lead in investigation area soil, groundwater, surface water, and sediment indicates that the lead is not associated with the MOGAS release.

Heavy-molecular-weight SVOCs (C16–C22 hydrocarbon range) with high boiling points were detected throughout the offsite area, but were not detected in onsite caprock groundwater. MOGAS constituents are typically restricted to VOCs and lightweight SVOCs (C3–C12 hydrocarbon range) with low boiling points. Boiling point distillation data for EJFDF MOGAS samples collected in 1971 confirm that the product released at the site did not contain heavy SVOCs. Therefore, the heavy SVOCs detected off site are not likely to be related to the MOGAS release. Heavy SVOCs are commonly associated with asphalt pavement, heavy fuel products, and combustion emissions (e.g., vehicle exhaust). Heavy SVOCs are relatively immobile in the aqueous phase due to their low solubility and high affinity for organic matter; this provides further evidence that the MOGAS release is not likely to be the SVOC source. Offsite sediment SVOC levels were similar to offsite surface soil SVOC levels, suggesting that the SVOCs are sorbed to soil particles.

Low levels of bis(2-ethylhexyl)phthalate (BEHP) were also detected at surface sampling locations throughout the offsite area. Relatively high BEHP concentrations were detected in sediment and surface water samples collected near a storm sewer outfall to the harbor. BEHP is a common contaminant in urban stormwater runoff; therefore, the MOGAS release is not likely to be the BEHP source.

Natural Attenuation of MOGAS Hydrocarbons in Caprock Groundwater

Soluble MOGAS constituents (primarily BTEX) that remain in on site subsurface soil may leach to the caprock water-bearing zone and migrate toward the offsite area in the aqueous phase. However, hydrocarbons dissolved in groundwater are subject to attenuation by natural processes, including biodegradation. The extent and magnitude of biodegradation were assessed by evaluating caprock groundwater electron acceptor concentrations (dissolved oxygen, nitrate, iron, sulfate, and carbon dioxide). Microorganisms that occur naturally in soil and groundwater consume electron acceptors as they degrade petroleum hydrocarbons. The core of the caprock groundwater contaminant plume strongly correlates with depleted electron acceptor concentrations—evidence that biodegradation is an important natural attenuation process at the EJFDF. Very significant reductions in caprock groundwater hydrocarbon concentrations were observed with both time and distance downgradient of the MOGAS release area. Phase II RI results indicate that natural attenuation reduces caprock groundwater total BTEX concentrations to less than 10 ppb within approximately 400 feet downgradient of the MOGAS source. Groundwater modeling results indicate that MOGAS constituents will not reach the offsite area at concentrations that would threaten human or ecological receptors, and that BTEX concentrations in onsite groundwater should reach very low levels within the next decade.

Offsite Transport of MOGAS Contaminants

Phase II RI data indicate that pathways for transport of residual onsite contamination to human or ecological receptors are either incomplete or insignificant. Groundwater sampling data indicate that MOGAS constituents have not migrated off site at significant levels. Furthermore, hydrogeological evidence and analytical data indicate that the caprock groundwater discharges directly to Pearl Harbor, and does not reach the ground surface in the watercress farm area. Caprock water table elevations are at least 2 feet below the bottoms of the watercress patches (which are irrigated with water from artesian wells screened in the deep, confined basal aquifer), and there is no evidence of

springs or seeps. Due to natural attenuation and dilution that occurs when caprock groundwater discharges to the harbor, it is highly unlikely that contaminants from the EJFDF could reach Pearl Harbor at concentrations that would pose risks to human or ecological receptors. Contaminants dissolved in the caprock groundwater cannot migrate downward to the confined basal aquifer (the main drinking water source for offsite farm residents). The hydraulic gradient across the low-permeability confining strata between the basal aquifer and the caprock water-bearing zone is directed upward; any leakage through the confining strata would therefore also be directed upward.

Human Health and Ecological Risks from Non-MOGAS-Related Contaminants

Risks associated with direct exposure to the non-MOGAS-related contaminants detected in the offsite area were assessed for offsite human receptors (farm workers, residents, and utility workers) and for ecological receptors. Results of the human health risk assessment indicate that offsite contaminants do not pose unacceptable risks to human receptors. Results of the ecological risk assessment indicate that offsite contaminants (non-site-related lead and SVOCs) may pose unacceptable risks to offsite ecological receptors; however, the risks are overestimated due to the use of maximum detected concentrations of chemicals of potential ecological concern.

Phase II RI Conclusions and Recommendations

Phase II RI results confirm the Phase I RI conclusion that the MOGAS constituents remaining at the site are not likely to threaten human health or the environment. An extensive body of groundwater monitoring data indicates that natural attenuation has greatly decreased caprock groundwater contaminant concentrations over the 28 years since the MOGAS release, and reduces concentrations to very low levels well before the groundwater reaches the downgradient site boundary. Maximum groundwater hydrocarbon concentrations detected during the Phase II RI are below chemical-specific applicable or relevant and appropriate requirements (ARARs) and to-be-considered (TBC) criteria identified for the caprock water-bearing zone. The caprock is not a current or potential future drinking water source, and dissolved hydrocarbons cannot migrate to the underlying confined basal aquifer. Therefore, National Recommended Water Quality Criteria and more stringent Hawaii Chronic Water Quality Standards were identified as chemical-specific ARARs. For those chemicals without ARARs, Hawaii Tier 1 action levels for sites where drinking water sources are not threatened and with less than 200 centimeters annual rainfall were identified as TBCs. Contaminant concentrations detected during the Phase II RI are compared to these risk-based screening criteria in Table ES-1.

Phase I and Phase II RI findings and risk assessment results provide strong evidence that MOGAS constituents remaining in subsurface soil and caprock groundwater near the MOGAS source pose no current or future human health or ecological threats. Therefore, no further action is recommended for the EJFDF.

Table ES-1: Summary of Phase II RI Analytical Results

Contaminant Type	Caprock Groundwater	Basal Groundwater	Subsurface Soil	Surface Soil	Sediment	Surface Water
MOGAS-Related						
BTEX	Below screening criteria	ND	Below screening criteria	ND	ND	ND
1,2- Dichloroethane	Below screening criteria	ND	Below screening criteria	ND	ND	ND
Light-end SVOCs	Below screening criteria	ND	Below screening criteria	ND	ND	Below screening criteria
Lead	Below screening criteria	ND	Below screening criteria	Detected but not MOGAS-related	Detected but not MOGAS-related	Detected but not MOGAS-related
Not MOGAS Related						
VOCs (laboratory contaminants)	Below screening criteria	ND	Below screening criteria	ND	Below screening criteria	Below screening criteria
Heavy-end SVOCs (including phthalates)	Below screening criteria	ND	Below screening criteria	Below human health screening criteria; above ecological screening criteria	Above screening criteria	Above screening criteria
Metals (including lead not MOGAS-related)	Above screening criteria	Below screening criteria	Below screening criteria	Below human health screening criteria; above ecological screening criteria	Above ecological screening criteria	Above ecological screening criteria

ND = not detected

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ACRONYMS AND ABBREVIATIONS

µg	microgram
°C	degrees Celsius
°F	degrees Fahrenheit
AFCEE	Air Force Center for Environmental Excellence
API	American Petroleum Institute
ARAR	applicable or relevant and appropriate requirement
ASTM	American Society for Testing and Materials
ATSDR	Agency for Toxic Substances and Disease Registry
AVGAS	aviation gasoline
BCF _e	soil-to-earthworm bioconcentration factor
BCF _i	surface water-to-aquatic invertebrate bioconcentration factor
BCF _p	soil-to-plant bioconcentration factor
BEHP	bis(2-ethylhexyl)phthalate
BERA	baseline ecological risk assessment
bgs	below ground surface
BTAG	Biological Technical Assistance Group
BTEX	benzene, toluene, ethylbenzene, and xylenes
BW	body weight
CAA	Clean Air Act
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CFR	Code of Federal Regulations
CLEAN	Comprehensive Long-Term Environmental Action Navy
CLP	Contract Laboratory Program
cm	centimeter
cm ²	square centimeter
cm ³	cubic centimeter
COC	chain of custody
COPEC	chemical of potential ecological concern
COPC	chemical of potential concern
CSM	conceptual site model
CTO	contract task officer
CWA	Clean Water Act
DCA	dichloroethane
DDE	dichlorodiphenyldichloroethylene
DDT	dichlorodiphenyltrichloroethane
DLNR	Department of Land and Natural Resources, State of Hawaii
DO	dissolved oxygen
DOH	Department of Health, State of Hawaii
DON	Department of the Navy, United States
DPC	decision point concentration
DPF	diet partitioning factor
DQO	data quality objective
Eco-SSL	ecological soil screening level
ED	effective dose
EJFDF	Ewa Junction Fuel Drumming Facility
EPA	Environmental Protection Agency, United States
EPC	exposure point concentration
ERA	ecological risk assessment
ER-L	effects range-low

ER-M	effects range-medium
ESA	Endangered Species Act
ESE	Environmental Science and Engineering, Inc.
FI	food intake
FISC	Fleet and Industrial Supply Center
gm	gram
HAR	Hawaii Administrative Rules
HCZM	Hawaii Coastal Zone Management Law
HEAST	Health Effects Assessment Summary Tables
HI	hazard index
HL	half-life
HLA	Harding Lawson Associates
HMW	high molecular weight
HQ	hazard quotient
hr	hour
HRA	health risk assessment
HRS	Hawaii Revised Statutes
HSA	hollow-stem auger
HWCS	Hawaii Well Construction Standards
IAS	initial assessment study
IC	indicator chemical
ID	identification
IDW	investigation-derived waste
ILM	Inorganic Laboratory Method
IRIS	Integrated Risk Information System
IRP	Installation Restoration Program
IEUBK	Integrated Exposure Uptake Biokinetic Model for Lead in Children
k	kilometer
kg	kilogram
K _{ow}	octanol-water partition coefficient
L	liter
LCC	Leeward Community College
LCS	laboratory control sample
LD	lethal dose
LMW	low molecular weight
LNAPL	light nonaqueous phase liquid
LOAEL	lowest-observed-adverse-effect level
m	meter
MCL	maximum contaminant level
MCLG	maximum contaminant level goal
MCP	Massachusetts Contingency Plan
mg	milligram
mg/kg-day	milligram per kilogram per day
MI	microwell
MOGAS	motor gasoline
MF	modifying factor
MFA	Masa Fujioka & Associates
MRL	method reporting limit
MS	matrix spike
MSD	matrix spike duplicate
msl	mean sea level

mV	millivolt
MW	monitoring well
NCP	National Oil and Hazardous Substances Contingency Plan
NEESA	Naval Energy and Environmental Support Activity
NFA	no further action
NOAA	National Oceanic and Atmospheric Administration
NOEC	no-observed-effect concentration
NOAEL	no-observed-adverse-effect level
NRC	National Research Council
NRWQC	National Recommended Water Quality Criteria (Federal Clean Water Act)
NTU	nephelometric turbidity unit
OLM	Organic Laboratory Method
PACDIV	Pacific Division, United States Navy
PACNAVFACENGCOM	Pacific Division, Naval Facilities Engineering Command
PAH	polynuclear aromatic hydrocarbon
PAL	performance acceptance limit
PARCC	precision, accuracy, representativeness, comparability, and completeness
PE	performance evaluation
PEL	probable effect level
PID	photoionization detector
ppm	parts per million
ppmv	parts per million by volume
PRE	preliminary risk evaluation
PRG	preliminary remediation goal
PVC	polyvinyl chloride
QC	quality control
RAGS	Risk Assessment Guidance for Superfund
RBCA	Risk-Based Corrective Action
RCRA	Resource Conservation and Recovery Act
RfC	reference concentration
RfD	reference dose
RI	remedial investigation
RME	reasonable maximum exposure
RPD	relative percent difference
RPF	relative potency factor
SAP	sampling and analysis plan
SARA	Superfund Amendments and Reauthorization Act
SDWA	Safe Drinking Water Act
sec	second
SERA	screening ecological risk assessment
SIM	selective ion monitoring
SLTH	Sunn, Low, Tom, and Hara
SMCL	secondary maximum contaminant level
SQB	sediment quality benchmark
SQC	sediment quality criteria
SSL	soil screening level
SUF	site use factor
SVOC	semivolatile organic compound
SW	solid waste
TBC	to be considered

TCA	trichloroethane
TCE	trichloroethene
TDS	total dissolved solids
TEL	threshold effect level
TFH	total fuel hydrocarbons
TMB	trimethylbenzene
TOC	total organic carbon
TPH	total petroleum hydrocarbons
TRV	toxicity reference value
TVH	total volatile hydrocarbons
UCL	upper confidence limit
UF	uncertainty factor
USC	United States Code
USDA	United States Department of Agriculture
USDW	underground source of drinking water
USFWS	United States Fish and Wildlife Service
UST	underground storage tank
VOC	volatile organic compound
WQS	water quality standards (Hawaii Department of Health)
yr	year

1. INTRODUCTION

Phase I of the Remedial Investigation (RI) for the Ewa Junction Fuel Drumming Facility (EJFDF), Fleet and Industrial Supply Center (FISC), Pearl Harbor, Oahu, Hawaii, was conducted in 1992–1995 (Ogden 1996). It focused primarily on the nature and extent of onsite contamination from a motor gasoline (MOGAS) release that occurred at the EJFDF in 1971.

Phase II of the RI continues the investigation in the onsite area and adds a detailed investigation of the offsite agricultural and wetland areas located downgradient of the EJFDF. The scope of the investigation was expanded to further evaluate the potential for contamination from the MOGAS release to impact human or ecological receptors in the offsite area.

This Phase II RI report has been prepared for the Pacific Division, Naval Facilities Engineering Command (PACNAVFACENGCOM) under the Comprehensive Long-Term Environmental Action Navy (CLEAN) II, contract no. N62742-94-D-0048, contract task order (CTO) no. 0033. The Phase II RI was conducted according to guidance presented in the *Navy/Marine Corps Installation Restoration Manual* (DON 1997) and *Guidance for Conducting Remedial Investigations and Feasibility Studies under CERCLA* (EPA 1988b).

1.1 PROJECT SETTING

As shown in Figure 1-1, the EJFDF is located north of the Middle Loch of Pearl Harbor, on the Island of Oahu, Hawaii. The southern boundary of the site is 250–700 feet from the shore of Middle Loch. The area investigated during the Phase II RI includes the 44-acre EJFDF site and the offsite area between the EJFDF and the shoreline. The location of the EJFDF relative to Middle Loch and the surrounding area is shown in Figure 1-2; the layout of the investigation area is shown in Figure 1-3.

The elevation of the Phase II RI investigation area ranges from sea level along the shore of Middle Loch to approximately 100 feet above mean sea level (msl) near the northern boundary of the EJFDF.

Structures at the EJFDF include two 585,000-gallon (88-foot-diameter, 13-foot-deep) concrete-lined underground storage tanks (USTs), a fuel drumming facility (Building 9), and associated piping. The USTs, designated S-26 and S-27, were used to store MOGAS and aviation gasoline (AVGAS). Locations of the USTs and other pertinent EJFDF features are illustrated in Figure 1-3. Vegetation has overgrown the structures due to inactivity at the site.

Agricultural activity in the agricultural and wetlands area south of the EJFDF is dominated by watercress cultivation. The watercress is grown in shallow ponds and patches (1–2 feet deep), which are filled with a few inches of gravel and flooded to a depth of 3–4 inches. Water from the ponds and patches and a stream adjoining the site drains to the Middle Loch of Pearl Harbor. A paved bicycle path parallels the shoreline and separates the agricultural area from marsh areas and mangrove swamps along the edge of the harbor.

1.2 EJFDF HISTORY

The EJFDF was constructed in 1943 as a fuel drumming and transportation terminal; it has been inactive since the early 1970s. According to a 1972 PACNAVFACENGCOM report (Mau 1972), vandals activated a UST S-26 fuel pump on 12 March 1971, releasing an estimated 315,000 gallons of MOGAS to the ground surface next to the UST. A pool of MOGAS 1–2 feet deep and approximately 150 feet in diameter was discovered the next morning. Navy personnel pumped as

much of the pooled surface fuel as possible—approximately 32,000 gallons—back into UST S-26; the remaining fuel infiltrated into the ground or evaporated.

According to the State of Hawaii Department of Health (DOH[DB11]), the EJFDF site is scheduled to be transferred to the State Hawaiian Home Lands Department. If the land transfer goes forward, the EJFDF site may be developed for residential purposes in the future. It is important to note, however, that the offsite area between the southern boundary of the EJFDF and Pearl Harbor is private property (not Navy property), and neither transfer nor development is planned.

1.3 PREVIOUS INVESTIGATIONS

Previous efforts to contain and remediate contamination associated with the 1971 MOGAS release and environmental investigations at the EJFDF are summarized below.

1.3.1 Initial Investigation and Interim Removal Actions—F. K. Y. Mau (1971–1972)

F. K. Y. Mau, a PACNAVFACENGCOM sanitary engineer, described the MOGAS release and initial efforts to recover or contain the MOGAS (Mau 1972). According to the report, the Navy drilled 24 monitoring wells (4-inch diameter) at the site to delineate the extent of MOGAS floating on the water table. Significant quantities of MOGAS were observed floating on the caprock water table in six of the monitoring wells. The maximum free product thickness, 5 feet, was observed in a monitoring well located approximately 100 feet downgradient of UST S-26. A 16-inch-diameter recovery well was installed at each of the six monitoring locations. Significant quantities of fuel were pumped from three of the recovery wells; however, recovery proved to be impractical at the other three recovery well locations, presumably due to the relatively impermeable nature of the surrounding soil. The Navy continued to monitor the horizontal extent and thickness of free product in the 4-inch diameter monitoring wells until late 1973.

Following recovery well installation, an interceptor trench was constructed along the southern boundary of the site to recover free product and prevent contaminants from migrating into the offsite agricultural and wetlands area. The approximate location of the trench is illustrated in Figure 1-3. The trench was approximately 27 feet deep and penetrated approximately 5 feet below the water table. The downgradient wall of the trench was lined with an impermeable membrane to prevent lateral movement of the MOGAS. A skimming tank was installed to recover free product floating on the water table. The trench was completed in late April 1971; at the same time, MOGAS was detected in monitoring holes approximately 200 feet upgradient of the southern site boundary. On 12 May 1971, free product was first observed in the trench, and recovery efforts were initiated. The field observations indicate that the trench was completed in time to intercept the free product before it could migrate off site.

1.3.2 Sunn, Low, Tom, and Hara (1974–1975)

According to the report of a 1974–1975 investigation by Sunn, Low, Tom, and Hara (SLTH), the recovery wells and interceptor trench were operated for approximately 1 year, after which the Navy estimated that approximately 100,500 gallons of fuel had been either recovered or evaporated (SLTH 1975). SLTH estimated the extent of the area originally contacted by free product to be approximately 180,000 square feet. Figure 1-4 shows the area originally contacted by free product, as indicated by field observations between 1971 and 1989 (the last year free product was observed at the site).



AR00029811



AR00029812

SLTH monitored the extent and thickness of free product in 1974 and 1975, and estimated that free product thickness decreased by approximately 0.5–1.0 feet per year between early 1971 and early 1975. By early 1975, measured free product thickness was at or very close to zero, except in two monitoring holes located immediately downgradient of UST S-26 (where thicknesses were approximately 0.3 and 0.8 feet). SLTH also collected soil samples from nine new soil borings and tested for fuel by chemical oxygen demand analysis. Fuel was detected in all but one soil sample. SLTH recommended extending and reactivating the interceptor trench to prevent contamination from migrating beyond the southern boundary of the site.

1.3.3 Naval Energy and Environmental Support Activity (1983)

The Naval Energy and Environmental Support Activity (NEESA) conducted an initial assessment study (IAS) in October 1983 (NEESA 1983). Although the EJFDF site was identified as potentially contaminated, a confirmation study was not recommended.

1.3.4 Environmental Science and Engineering (1989)

In October and November 1989, Environmental Science and Engineering (ESE) collected subsurface soil samples from borings drilled around the perimeters of UST S-26 and UST S-27 (ESE 1990). Elevated concentrations of total petroleum hydrocarbons (TPH), toluene, ethylbenzene, and xylene were detected in subsurface soil surrounding UST S-26. TPH, toluene, ethylbenzene, and xylene were also detected in subsurface soil surrounding UST S-27, but concentrations were below sample quantitation limits.

1.3.5 Harding Lawson Associates (1988–1990)

Harding Lawson Associates (HLA) reported that significant concentrations of lead and benzene, toluene, ethylbenzene, and xylenes (BTEX) were detected in subsurface soil and groundwater samples from nine new borings/monitoring wells and several of the previously existing monitoring wells at the site (HLA 1990). HLA concluded that MOGAS-contaminated soil may slowly release soluble hydrocarbons and lead to the shallow caprock water-bearing zone. The maximum total BTEX concentration detected in the caprock groundwater (10.07 milligrams per liter [mg/L]) was detected in a sample collected in March 1989 from monitoring well (MW)-2, located immediately adjacent to UST S-26. Floating free product was observed in only one of the monitoring wells, MW-6, located at the northeast end of the interceptor trench. The maximum free product thickness measured in MW-6 was 0.18 feet. HLA did not detect BTEX or lead in groundwater samples from two offsite artesian wells that tap the deep confined basal aquifer that underlies and is confined by caprock sediments. HLA recommended modifications to the existing interceptor trench, recovery of free product from MW-6, and an assessment of risks to human health and the environment.

1.3.6 Masa Fujioka & Associates (1991–1992)

In February and March 1992, Masa Fujioka & Associates (MFA) completed 10 hand-auger soil borings, installed 11 borings/monitoring wells, and collected 61 soil vapor probe measurements (MFA 1992). Soil, groundwater, and soil vapor sampling results indicated that contaminants from the 1971 MOGAS release still existed in both soil and groundwater, particularly in the area downgradient of the contaminant source, UST S-26. MFA also reported that soil and groundwater contamination were detected in monitoring well EJ-21 (downgradient of UST S-27), but not in EJ-22 (upgradient of UST S-27). MFA suggested this could indicate leakage from UST S-27. Minor concentrations of TPH were detected in groundwater samples collected in the northeast corner of the site; however, soil contamination was not detected, suggesting that groundwater contamination in this area may be due to an offsite source.

1.3.7 Phase I Remedial Investigation—Ogden (1992–1995)

Phase I RI field activities included a soil gas survey, hydrogeologic investigation, and chemical analysis of surface soil, subsurface soil, and groundwater samples (Ogden 1996). The field data were evaluated and interpreted to characterize the nature and extent of contamination, assess human health and ecological risks, and make recommendations for further action.

Soil Gas. Soil gas samples were collected at 44 locations from depths up to 27 feet below ground surface (bgs). Volatile hydrocarbons were detected at only two locations, both downgradient of UST S-26. The maximum detected total volatile hydrocarbon (TVH) concentration was only 2.0 parts per million by volume. BTEX compounds were not detected in the soil gas. The report concluded that contaminants transported via the air pathway are not likely to threaten human or ecological receptors, because vapor-phase contaminant concentrations detected in the subsurface have been very low.

Groundwater. Groundwater samples and water level measurements were collected from 21 onsite wells that penetrate the caprock water-bearing zone both up- and downgradient of UST S-26. Four groundwater sampling rounds were completed over a 27-month period (May 1992 to August 1994), at intervals of approximately 9 months. The caprock groundwater flows generally southward, from the EJFDF toward the offsite agricultural and wetlands area and the shore of Pearl Harbor. Free product has not been detected in any monitoring wells since the HLA investigation in 1989. Therefore, the Phase I RI report concluded that migration of dissolved (aqueous-phase) MOGAS constituents (such as BTEX) within the caprock water-bearing zone is the only pathway at the EJFDF likely to transport significant quantities of contaminants.

Caprock groundwater is not used for human consumption in the vicinity of the site. In addition, caprock groundwater in this area is not considered a viable source of potable water due to the low hydraulic conductivity associated with the water-bearing zone and relatively high concentrations of total dissolved solids (TDS). Caprock groundwater conditions beneath the EJFDF are discussed in detail in Section 3.8.2.

The following aqueous-phase contaminants were detected in groundwater samples collected during the Phase I RI monitoring program:

- TPH
- Total lead
- Volatile organic compounds (VOCs), as follows:
 - methylene chloride
 - acetone
 - chloromethane
 - hexane
 - 1,2-dichloroethane (1,2-DCA)
 - trichloroethane (TCA)
 - benzene
 - toluene
 - ethylbenzene
 - meta-, para- and ortho-xylene
- Semivolatile organic compounds (SVOCs), as follows:
 - phenol
 - acenaphthalene

- | | |
|-----------------------|-------------------------------------|
| — 4-methylphenol | — diethylphthalate |
| — 2,4-dimethylphenol | — fluorene |
| — naphthalene | — n-nitrosodiphenylamine |
| — methylnaphthalene | — phenanthrene |
| — 2-chloronaphthalene | — di-n-butylphthalate |
| — dimethylphthalate | — bis(2-ethylhexyl)phthalate (BEHP) |

The common laboratory contaminants methylene chloride and acetone were detected at low concentrations and apparently do not represent an onsite source. Chloromethane and TCA were each detected only in single groundwater samples. Neither chloromethane nor TCA are compounds associated with MOGAS. This lack of association and the limited distribution of these two VOCs suggest that they are not directly related to the MOGAS spill. The other listed VOCs and the naphthalene and phenolic compounds listed as SVOCs are commonly present in gasoline; they are therefore likely related to the 1971 MOGAS release. The other SVOCs, including phthalates, acenaphthalene, fluorene, and phenanthrene, that were detected in groundwater samples collected downgradient of UST S-26 may be related to other petroleum product releases in the site vicinity.

BTEX compounds are considered the contaminants of greatest concern at the EJFDF due to their toxicity and potential to migrate in the aqueous phase. Benzene is of particular concern due to its relatively high solubility, high initial concentration, toxicity, persistence, and mobility. Elevated BTEX concentrations were detected in Phase I RI groundwater samples collected from monitoring wells that penetrate the caprock water-bearing zone downgradient of UST S-26. The maximum concentration of total BTEX in groundwater (8.53 mg/L) was detected in a sample collected in May 1992 from MW-2, located directly adjacent to UST S-26. The maximum concentration of total BTEX detected in a sample collected in May 1992 at MW-4 was 0.331 mg/L. MW-4 is located just within the site boundary, approximately 700 feet downgradient of UST S-26. The reduction in total BTEX concentrations suggests that significant natural attenuation occurs as the contaminants migrate downgradient.

The maximum lead concentration (325 micrograms per liter [$\mu\text{g/L}$]) was detected in a groundwater sample collected from a monitoring well downgradient of UST S-26. Relatively high lead concentrations were also detected in several other wells downgradient of UST S-26. Because total lead concentrations in samples collected from the "background" well (MW-20) ranged from less than 1.0 $\mu\text{g/L}$ to 2.6 $\mu\text{g/L}$, the Phase I RI concluded that the lead detected downgradient of UST S-26 may be attributable to the 1971 MOGAS release, leaks from onsite pipelines, or leaking regional distribution pipelines upgradient of the EJFDF.

Although contaminant concentrations detected in groundwater samples collected on site have declined in the years since the release, temporary increases have been observed when sampling has been conducted during wet seasons. The Phase I RI report suggests that these temporary increases may be the result of one of the following:

- Increased leaching of contaminants from the vadose zone due to rainwater infiltration
- Increased contaminant dissolution due to the greater volume of contaminated soil in contact with groundwater when the groundwater table is high

Contaminants related to the MOGAS release were not detected in groundwater samples collected from the artesian wells that tap the confined basal aquifer downgradient of the site. The hydrogeologic characteristics of the investigation area tend to prevent leakage from the caprock water-bearing zone into the underlying basal aquifer. A thick sequence of low-permeability silty clays isolates the caprock water-bearing zone from the basal aquifer. In addition, the hydraulic gradient across the low-permeability confining strata between the two groundwater bodies is directed upward—from the basal aquifer toward the caprock water-bearing zone. Any leakage through the confining strata would, therefore, also be directed upward. The caprock water-bearing zone and the underlying confined basal aquifer are described in detail in Section 3.8.

Phase I RI sampling results indicate that caprock groundwater contaminant concentrations decrease to very low levels as the plume migrates downgradient. In addition, the Phase I RI report suggests that dilution by uncontaminated artesian well water used to irrigate the offsite agricultural area or seawater would greatly reduce concentrations of any groundwater contaminants that may be discharged from the caprock water-bearing zone to the agricultural and wetlands area or the Middle Loch of Pearl Harbor.

Soil. Subsurface soil samples were collected on site from seven trenches and 14 borings during the Phase I RI. Compounds associated with MOGAS were detected at concentrations below action levels established by the State of Hawaii Department of Health (DOH) as well as preliminary remediation goal (PRG) criteria established by Region IX of the United States Environmental Protection Agency (EPA). The maximum total fuel hydrocarbon (TFH) concentration detected among the trench soil samples was 18 milligrams per kilogram (mg/kg). The Phase I RI report suggests that any light nonaqueous-phase liquid (LNAPL) (i.e., free product) that remains within vadose zone soil after more than 25 years is likely to be relatively immobile in the nonaqueous phase. However, soluble contaminants may enter the aqueous phase as residual suspended or sorbed MOGAS constituents are leached from source area soil (i.e., subsurface soil in the area adjacent to and downgradient of UST S-26).

The Phase I RI and previous studies have demonstrated that contaminant concentrations in onsite caprock groundwater have decreased over the years since the MOGAS release, and that contaminant concentrations in source area soil have also been decreasing. Mechanisms likely to be contributing to the observed reduction in soil contamination include leaching, evaporation, and biodegradation. Phase I RI sampling results suggest that residual suspended or sorbed MOGAS constituents in soil within and just above the capillary fringe represent the only significant contaminant source remaining at the site.

Other Potential Contaminant Sources. Although the major source of contamination at the EJFDF appears to be the 1971 MOGAS release, several other potential contaminant sources were identified in the Phase I RI report. Sections of a petroleum, oil, and lubricant transmission pipeline operated by the United States Department of Defense are within 1 mile of the northern boundary of the EJFDF. Between 1949 and 1955, this pipeline was reportedly the source of at least six leaks, one of which was estimated at approximately 300,000 gallons of AVGAS (ESE 1990). An underground fuel pipeline (operated by Tesoro Hawaii) that runs along the southern boundary of the site conveys a variety of petroleum products, including diesel, gasoline, and jet fuel. Potential contaminant sources also include leakage from UST S-27, underground fuel lines, and valve boxes at the site. Leaks from petroleum product pipelines (operated by Chevron USA and Navy FISC) that parallel the bicycle path along the shore of Pearl Harbor represent another potential source of contamination. In 1987, a pipeline rupture released approximately 120,000 gallons of Jet A fuel to a wildlife refuge (Waiawa

Unit of the Pearl Harbor National Wildlife Refuge) located near the Middle Loch shoreline, east of the offsite agricultural and wetlands area (see Figure 1-2).

Human Health Risk Assessment (HRA). The Phase I RI HRA assessed human health risks that may exist if remedial actions or institutional controls are not implemented. The HRA combined results from exposure and toxicity assessments to evaluate both individual and population risks associated with complete or potentially complete exposure pathways. HRA findings indicate that the dermal and ingestion exposure pathways associated with onsite surface soil contamination, potential contamination in the Middle Loch of Pearl Harbor, and potential contamination in the agricultural and wetlands area do not pose significant risks to human health. Onsite contamination and potential volatilization of contaminants from the watercress ponds downgradient of the site are unlikely to pose significant human health risks via the inhalation exposure pathway. Cumulative reasonable maximum exposure (RME) risks for all receptors were found to be at least two orders of magnitude below trigger levels for remediation (an excess cancer risk of 1×10^{-4} and a hazard index of 1).

Ecological Risk Assessment (ERA). Chemicals of potential ecological concern (COPECs) and potential ecological receptors were identified during the Phase I RI. An ERA was then conducted to identify complete or potentially complete exposure pathways and to assess risks to ecological receptors, both on site and in the offsite agricultural and wetlands area. The ERA indicates that onsite soil is not likely to pose risks to terrestrial receptors. Onsite terrestrial species are common, non-native urban species of little ecological or social importance. The ERA concluded that COPECs detected in the caprock groundwater may be transported to the marine environment in the Middle Loch of Pearl Harbor. However, natural attenuation along the groundwater flow path and dilution that occurs when the groundwater is discharged to Middle Loch will tend to minimize risk to ecological receptors. ERA risk estimates indicate minimal potential for adverse effects to either marine invertebrates or shorebirds, even if it is assumed that COPECs in caprock groundwater are diluted only after they enter Middle Loch.

Recommendations. Phase I RI fate and transport calculations indicated no potential for future offsite migration of the caprock groundwater contaminants detected during Phase I RI groundwater sampling. However, the report recommended installation of additional monitoring wells in the agricultural and wetlands area downgradient of the site to verify that offsite caprock groundwater has not been impacted. The report also recommended long-term monitoring of onsite and offsite wells to confirm that EJFDF caprock groundwater contaminants will not migrate off site in the future.

1.4 OBJECTIVES

Primary objectives of the Phase II RI are as follows:

- Assess the nature and extent of groundwater contamination, both within the boundaries of the EJFDF and in the agricultural and wetlands area between the site and the Middle Loch of Pearl Harbor.
- Assess the nature and extent of petroleum hydrocarbon and lead contamination in surface and subsurface soil in the agricultural and wetlands area.
- Assess the nature and extent of petroleum hydrocarbon and lead contamination in surface water and sediments in the agricultural and wetlands area.
- Compare the concentrations of detected contaminants to applicable or relevant and appropriate requirements (ARARs), or to-be-considered (TBC) criteria.

- Assess potential migration pathways for identified contamination, with emphasis on the potential for contaminants associated with the 1971 MOGAS spill to migrate with groundwater either in the aqueous phase or as free product.
- Evaluate potential hazards to human and ecological receptors associated with identified contamination.
- Assess the need for remedial action.
- Identify preliminary remedial alternatives for the site.

2. FIELD METHODS AND PROCEDURES

The flow chart presented in Figure 2-1 provides an overview of the Phase II RI field sampling program. The primary objective of the Phase II RI field investigation was to acquire additional data needed to evaluate the potential impact of contaminants from the EJFDF MOGAS release on human and ecological receptors in the offsite area downgradient of the site. In addition to data regarding contaminant concentrations in groundwater, hydrogeochemical data were collected to evaluate natural attenuation processes along the groundwater flow path. Potential contamination in offsite soil, sediment, and surface water was also investigated.

Phase II RI field activities were completed in two stages:

- Stage I (8 June–24 July 1998)—an ecological receptor and drainage pattern survey, surface water and sediment investigation, surface and subsurface soil investigation, and the first round of groundwater sampling
- Stage II (26 April–14 May 1999)—the second round of groundwater sampling

Field activities were documented in the field logbooks presented in Appendix A.

The following tasks were accomplished during the field investigation:

- Subsurface utility clearance at all boring locations
- Ecological and surface water drainage survey
- Surface water and sediment sampling at ten locations in the offsite area
- Surface soil sampling at five locations in the offsite area
- Subsurface soil sampling in 26 direct-push borings in the offsite area
- Subsurface soil sampling in four hollow-stem auger (HSA) borings in the offsite area
- Installation and development of twelve 1.5-inch-diameter microwells in the offsite area
- One round of groundwater sampling in the twelve microwells
- Installation and development of four 4-inch-diameter monitoring wells in the offsite area
- Two rounds of groundwater sampling in the four offsite and 21 onsite monitoring wells
- Groundwater sampling in three offsite artesian irrigation wells
- Topographic and sampling location survey
- Equipment decontamination
- Instrument calibration
- Investigation-derived waste (IDW) management and disposal

Unless otherwise stated, all field activities were conducted in accordance with the project field sampling and analysis plan (SAP) (Earth Tech 1998) and standard operating procedures (SOPs) from the *Project Procedures Manual*, U.S. Navy Pacific Division (PACDIV) Installation Restoration Program (IRP) (DON 1996, 1998).

2.1 SUBSURFACE UTILITY CLEARANCE SURVEY

To avoid damage to utilities or other subsurface structures during direct-push and HSA drilling, utilities were surveyed during 8–13 June 1998, in accordance with PACDIV IRP Procedure I-A-6, *Utility Clearance*, and I-B-2, *Geophysical Testing Procedures*. Existing utility maps were reviewed, and each boring location was surveyed by geophysical methods. Utility clearance survey notes and maps are presented in Appendix B.

The following geophysical instruments were used in the survey:

- Geonics EM-31 electromagnetic locator
- Radio Detection RD-400 electromagnetic locator
- Schonstedt GA-52B magnetic locator

2.2 ECOLOGICAL AND SURFACE WATER DRAINAGE SURVEY

An ecological and surface water drainage survey was conducted in the offsite agricultural and wetlands area during 8–9 June 1998. The survey focused on the watercress ponds, marsh areas, mangrove swamps, and harbor-edge habitats. Ecological receptors and potential exposure pathways were identified, and surface water drainage patterns were evaluated. To assess potential ecological threats posed by migration of contaminants from the EJFDF and to select surface water and sediment sampling locations, areas of potentially impacted surface water or sediment were identified. The survey also attempted to locate groundwater seeps or springs that may discharge caprock groundwater in the offsite area.

2.3 SURFACE WATER AND SEDIMENT SAMPLING

Surface water and sediment samples were collected in the watercress farm ponds and other areas draining into the Middle Loch of Pearl Harbor (e.g., mud flat and mangrove areas) to investigate the potential impact of contaminants from the EJFDF on surface water and sediment in the offsite area. Samples were collected at the 10 locations shown in Figure 2-2 on 30 June, 1 July, and 6–7 July 1998. At least one surface water sample and one sediment sample were collected at each of the ten locations.

Surface water samples were collected by submerging the mouth of the sampling container and allowing water to flow gently into the container, in accordance with PACDIV IRP Procedure I-B-4, *Surface Water Sampling*. Each water sample was tested in the field for dissolved oxygen, redox potential, conductivity, temperature, and pH with a groundwater parameter multiprobe. Sediment samples were collected with a stainless-steel hand trowel, in accordance with PACDIV IRP Procedure I-B-5, *Subaqueous Sediment Sampling*, and placed on ice in a cooler for transport to the analytical laboratory.

Samples were labeled, handled, and shipped to the analytical laboratory in accordance with the procedures listed in Section 2.6. Each surface water or sediment sample was analyzed by the methods listed in Table 2-1. The sediment samples were analyzed for polynuclear aromatic hydrocarbons (PAHs) by National Oceanic and Atmospheric Administration (NOAA) status and trends methods (Lauenstein and Cantillo 1993) to achieve the low detection limits necessary to compare data to the ecological screening criteria proposed by Long et al. (1995). Surface water and sediment sampling results are presented in Section 4.1.

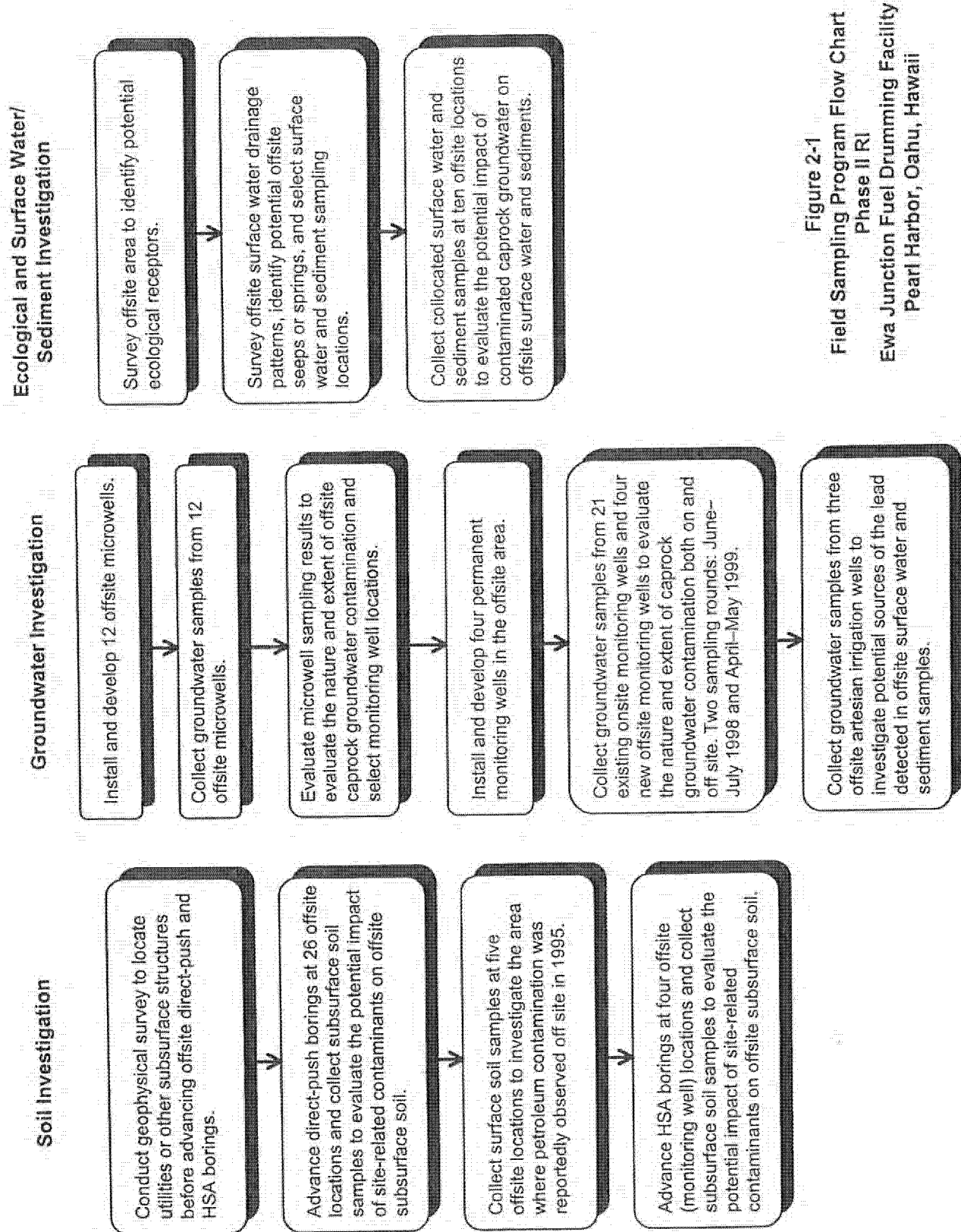


Figure 2-1
Field Sampling Program Flow Chart
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

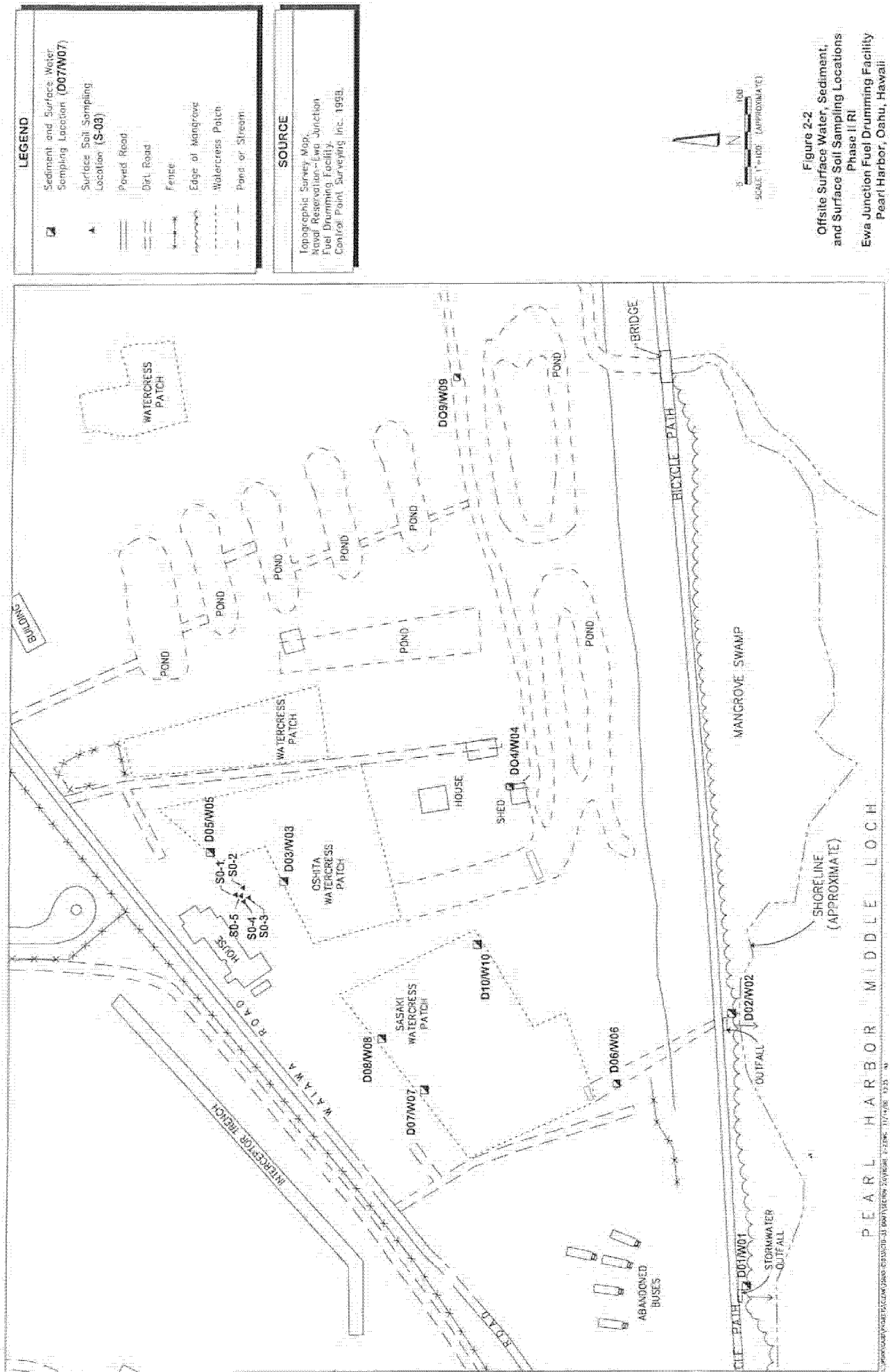


Table 2-1: Surface Water and Sediment Sample Chemical Analysis

Analytical Method	Analytical Parameters
CLP OLM03.1	VOCs
	SVOCs
EPA 8015B	TFH-gasoline (volatile)
	TFH-diesel (extractable)
EPA 8270 SIM ^a	PAHs
CLP ILM04.0	Total lead
EPA 9060	Total organic carbon

CLP = Contract Laboratory Program

TFH = total fuel hydrocarbons

SIM = selective ion monitoring

ILM = Inorganic Laboratory Method

^a Method used for sediment samples only.

2.4 SOIL INVESTIGATION

Surface and subsurface soil samples were collected in the offsite area to assess potential soil contamination related to the EJFDF MOGAS release, quantify geotechnical parameters that may influence contaminant transport, and aid in selecting appropriate locations for offsite groundwater monitoring wells. The soil sampling program included the following:

- Surface soil sampling
- Direct-push subsurface soil sampling
- HSA subsurface soil sampling

Samples were labeled, handled, and shipped to the analytical laboratory in accordance with the procedures listed in Section 2.6. The HSA boring soil samples were analyzed for chemical constituents and tested for geotechnical parameters. Surface soil samples and direct-push soil samples were analyzed for chemical constituents only. The chemical analytes are listed in Table 2-2; the geotechnical parameters are listed in Table 2-3. Surface soil samples were analyzed for PAHs by NOAA status and trends methods (Lauenstein and Cantillo 1993) to achieve the low detection limits necessary to compare data to the ecological screening criteria proposed by Long et al. (1995).

Table 2-2: Soil Sample Chemical Analysis

Analytical Method	Analytical Parameters
CLP OLM03.1	VOCs
	SVOCs
EPA 8015B	TFH-gasoline (volatile)
	TFH-diesel (extractable)
EPA 8270C SIM ^a	PAHs
CLP ILM04.0	Total lead

^a Method used for surface soil samples only.

Table 2-3: Soil Sample Geotechnical Testing

Testing Method	Geotechnical Parameters
ASTM D5084-90	Hydraulic conductivity
API RP40	Air permeability
ASTM D2937 and ASTM D2216	Bulk density soil moisture porosity
ASTM D422	Particle size distribution
EPA 9080	Cation exchange capacity
ASTM D422 and ASTM D4318	Soil classification
ASTM D4318	Plasticity index

API = American Petroleum Institute

ASTM = American Society for Testing and Materials

2.4.1 Surface Soil Sampling

Surface soil samples were collected at five offsite locations (see Figure 2-2) on 8 July 1998 to investigate petroleum contamination reportedly observed in August 1995 during excavation of a sewer line trench. Each soil sample was collected at a depth of 0.5 feet or less with a stainless-steel hand trowel, in accordance with PACDIV IRP Procedure I-B-1, *Soil Sampling*. Soil samples were placed in pre-cleaned, wide-mouthed glass jars (provided by the analytical laboratory), labeled, and immediately placed on ice in a cooler for transport to the analytical laboratory. Contaminant concentrations were quantified by the analytical methods listed in Table 2-2. Surface soil sampling results are presented in Section 4.1.

2.4.2 Direct-Push Soil Sampling

Subsurface soil samples were collected at 26 offsite direct-push boring locations (see Figure 2-3) during 11–22 June 1998. Direct-push soil sampling was planned for 30 locations; however, the required sampling depths could not be reached at four locations at the west end of Waiawa Road, due to obstruction by subsurface rubble and debris used as fill material. As shown in Table 2-1, boring depths ranged from 8 to 31 feet bgs. Twelve of the 26 borings were converted to 1.5-inch diameter microwells.

Subsurface soil samples were collected in stainless-steel sleeves using a direct-push drilling rig equipped with a piston assembly and split-spoon sampler (2-inch diameter by 2-foot length), in accordance with PACDIV IRP Procedure I-H, *Direct Push Sampling Techniques*. Drilling and sampling equipment was decontaminated by the procedures outlined in Section 2.9. The direct-push boring samples were examined and logged by a field geologist in accordance with PACDIV IRP Procedure I-E, *Soil and Rock Classification*. Boring logs are presented in Appendix C. Each sample was screened for VOCs with a photoionization detector (PID). A portion of the sample was placed in a quart-sized resealable plastic bag, sealed, broken up, and left to warm in the sun for 5 minutes. The PID probe was then inserted into the bag and the detected VOC concentration was recorded on the boring log. The sample-containing stainless-steel sleeves were immediately capped with Teflon sheets and clean plastic end caps, sealed with tape, labeled, and placed on ice in a cooler.

Soil samples for chemical analysis were collected from the capillary fringe and intervals with elevated PID readings. Contaminant concentrations were quantified by the analytical methods listed in Table 2-4. Direct-push subsurface soil sampling results are presented in Section 4.2.

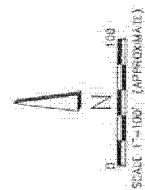
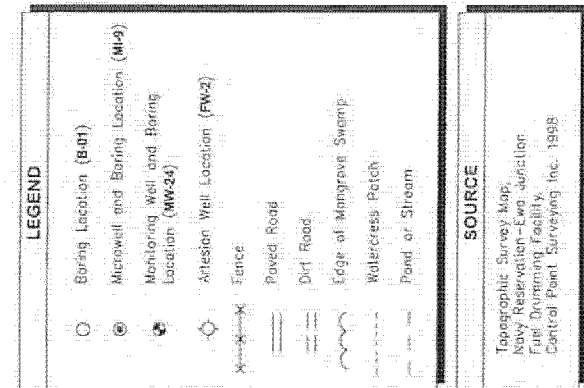
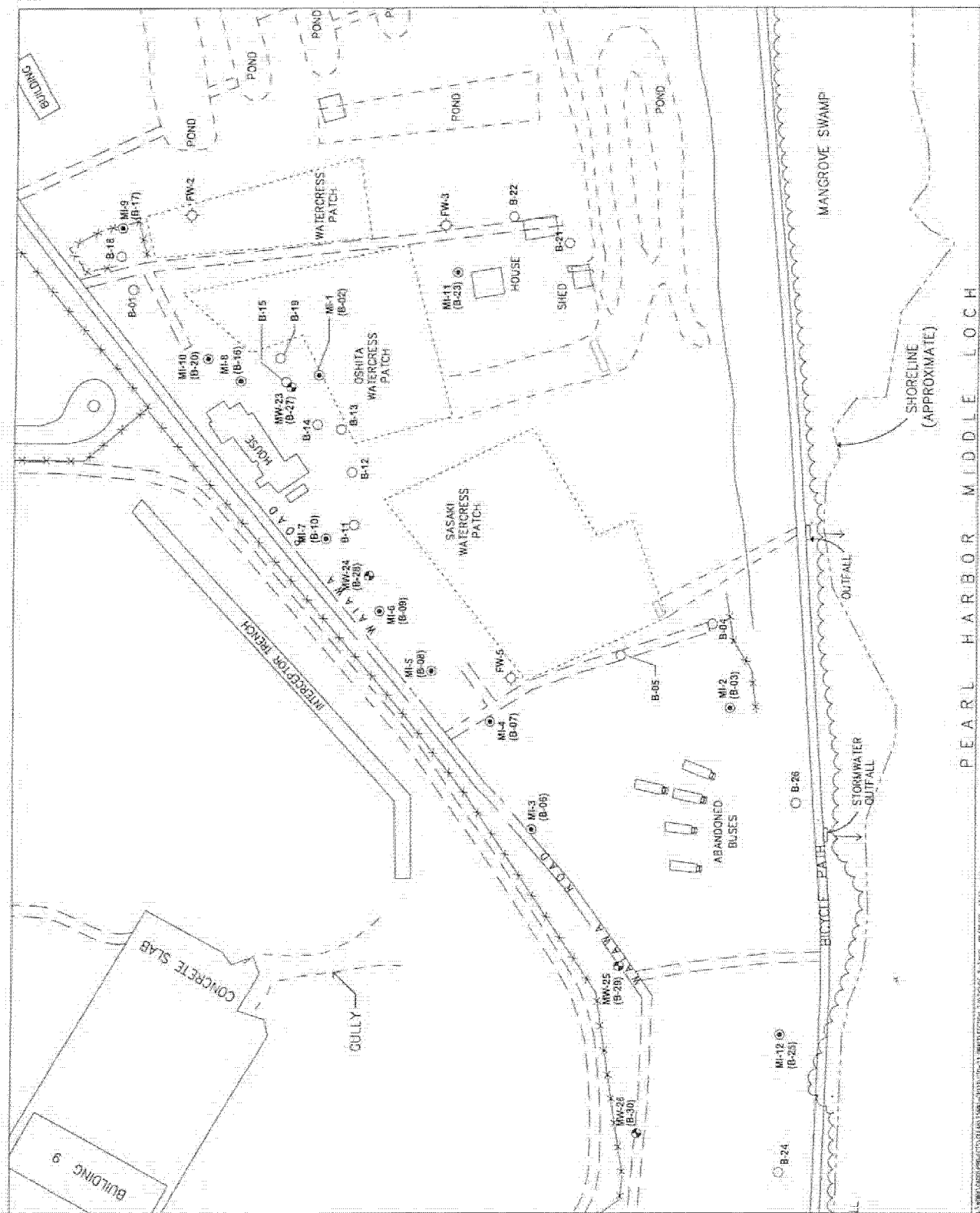


Figure 2-3
Offsite Boring, Monitoring Well,
Microwell, and Artesian Well Locations
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



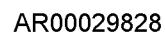


Table 2-4: Summary of Direct-Push Borings and Associated Microwells

Boring Number	Total Depth of Boring (feet bgs)	Converted to Microwell	Microwell Number	Total Depth of Microwell (feet bgs)
B01	19.0	No	n/a	n/a
B02	24.5	Yes	MI-1	24.5
B03	18.5	Yes	MI-2	18.5
B04	22.5	No	n/a	n/a
B05	24.0	No	n/a	n/a
B06	25.0	Yes	MI-3	25.0
B07	22.0	Yes	MI-4	22.0
B08	26.0	Yes	MI-5	26.0
B09	27.5	Yes	MI-6	25.0
B10	24.0	Yes	MI-7	24.0
B11	18.5	No	n/a	n/a
B12	12.5	No	n/a	n/a
B13	20.0	No	n/a	n/a
B14	19.5	No	n/a	n/a
B15	24.0	No	n/a	n/a
B16	28.0	Yes	MI-8	28.0
B17	24.0	Yes	MI-9	24.0
B18	24.0	No	n/a	n/a
B19	22.0	No	n/a	n/a
B20	31.0	Yes	MI-10	31.0
B21	19.0	No	n/a	n/a
B22	28.0	No	n/a	n/a
B23	22.5	Yes	MI-11	22.5
B24	10.0	No	n/a	n/a
B25	14.0	Yes	MI-12	14.0
B26	8.0	No	n/a	n/a

n/a = not applicable

2.4.3 Hollow-Stem Auger Soil Sampling

Subsurface soil samples were collected from four HSA borings completed in the offsite area (Figure 2-3) during 6–10 July 1998. As shown in Table 2-5, boring depths ranged from 28.5 to 35.0 feet bgs. Each boring was converted to a 4-inch monitoring well.

Table 2-5: Summary of HSA Borings and Associated Monitoring Wells

Boring Number	Total Depth of Boring (feet bgs)	Monitoring Well Number	Total Depth of Monitoring Well (feet bgs)
B27	28.5	MW-23	28.5
B28	35.0	MW-24	35.0
B29	32.0	MW-25	32.0
B30	30.0	MW-26	30.0

The borings were drilled with 12-inch-outer-diameter HSAs. Soil samples were recovered as the borings were advanced using a split-barrel sampler (2-inch diameter by 2-foot length) fitted with stainless-steel sleeves, in accordance with PACDIV IRP Procedure I-B-1, *Soil Sampling*. Drilling and sampling equipment was decontaminated by the procedures outlined in Section 2.9. Each sample was examined by a field geologist and logged according to PACDIV IRP Procedure I-E, *Soil and Rock Classification*. Boring logs are presented in Appendix C. Samples were inspected in the field for visible evidence of contamination (e.g., discoloration or sheen) and screened for VOCs by the procedure outlined in Section 2.4.2. The sample-containing stainless-steel sleeves were immediately capped with Teflon sheets and clean plastic end caps, sealed with tape, labeled, and placed on ice in a cooler.

At least three soil samples were selected from each boring for chemical analysis. Analytical samples were selected from the following locations:

- The unsaturated zone
- The capillary fringe zone
- The saturated zone
- Intervals with elevated VOC concentrations as detected by PID

Contaminant concentrations were quantified by the analytical methods listed in Table 2-2. One sample from the capillary fringe zone in each boring was submitted for geotechnical testing by the methods listed in Table 2-3. HSA subsurface soil sampling results are presented in Section 4.2.

2.5 GROUNDWATER INVESTIGATION

Primary objectives of the Phase II RI groundwater investigation are to define the extent of the caprock groundwater contaminant plume both on site and off site, and to evaluate the fate and transport of aqueous-phase contaminants. Groundwater samples were collected both upgradient and downgradient of the MOGAS release area, from the offsite monitoring wells and microwells shown in Figure 2-3, and from the onsite monitoring wells shown in Figure 2-4. Water levels were measured in each well with an electronic water-level indicator to define the caprock water table (water level data are presented in Section 3.8.2.1). During the first sampling round (summer 1998), caprock groundwater samples were collected from 12 microwells and four monitoring wells in the offsite area, and from 21 onsite monitoring wells. During the second sampling round (spring 1999), groundwater samples were collected from the 21 onsite monitoring wells, four offsite monitoring wells, and three offsite flowing (artesian) wells screened in the confined basal aquifer.

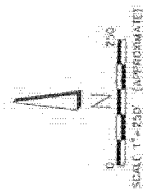
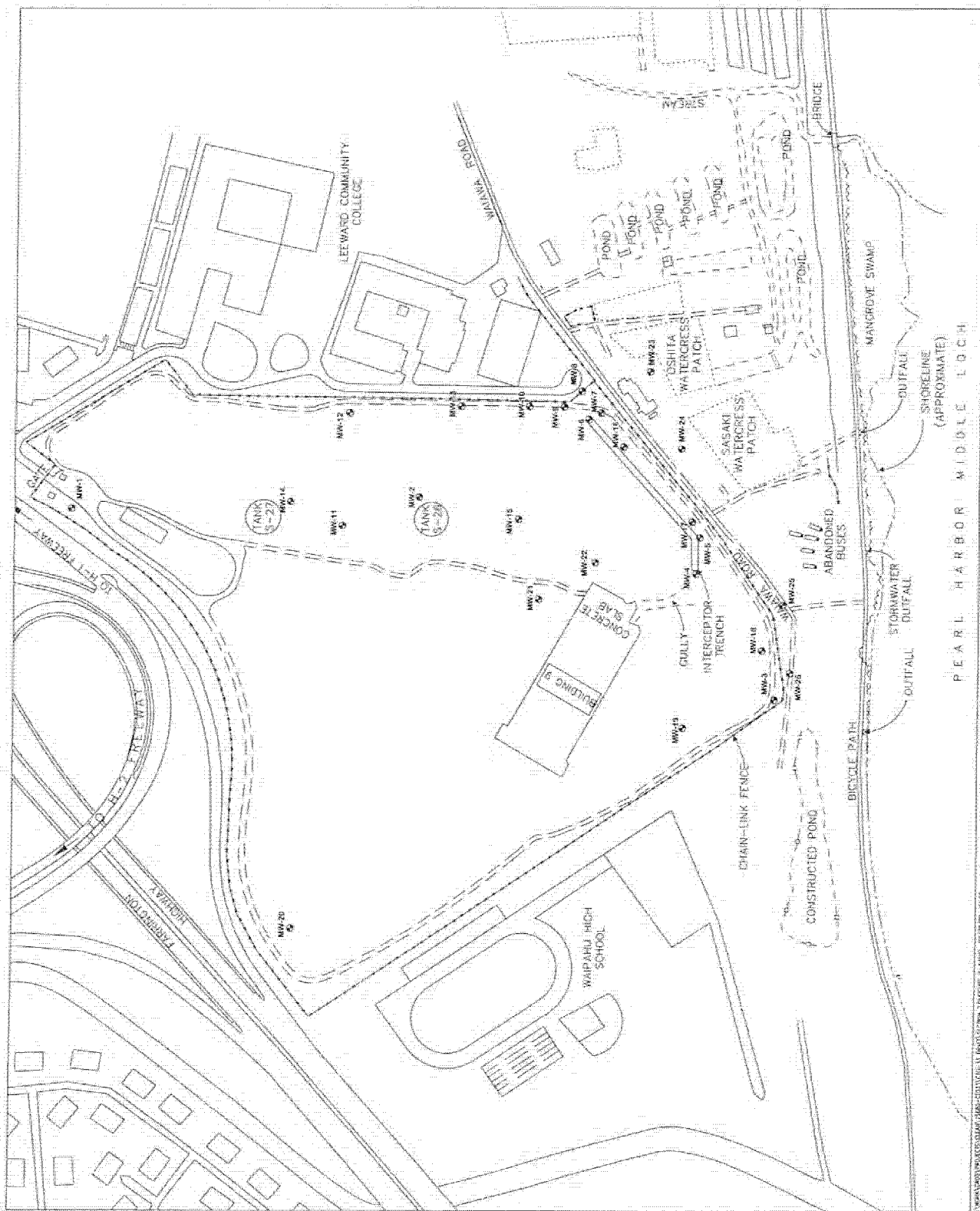


Figure 2-4
Onsite Monitoring Well Locations
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



Samples were labeled, handled, and shipped to the analytical laboratory in accordance with the procedures listed in Section 2.6. The groundwater samples were analyzed by the methods listed in Table 2-6 to quantify contaminant concentrations and hydrogeochemical parameters that may influence natural attenuation. Ferrous iron concentrations were quantified in the field with a Hach colorimeter (Model IR-18C). Dissolved oxygen, redox potential, conductivity, temperature, pH, and turbidity were quantified in the field with a groundwater parameter multiprobe.

Table 2-6: Groundwater Sample Analysis

Analytical Methods (Round One: June–July 1998)	Analytical Methods (Round Two: April–May 1999)	Analytical Parameters
CLP OLM03.1	EPA 8260B	VOCs
	EPA 8270	SVOCs
EPA 8015B	EPA 8015B	TFH-gasoline (volatile)
		TFH-diesel (extractable)
EPA 9060	EPA 9060	Total organic carbon
EPA 8260A	EPA 8260B	Trimethylbenzenes
EPA 300	EPA 300	Sulfate
		Chloride
EPA 353.2	EPA 353.3	Nitrate + Nitrite
Standard Methods 3500-Fe D	Standard Methods 3500-Fe D	Ferrous iron ^a
EPA RSKOP-175 Modified ^b	EPA 3810	Methane
EPA 310.2	EPA 310.2	Total alkalinity
EPA 340.2	EPA 340.2	Fluoride
EPA 425.1	EPA 425.1	Surfactants
EPA 160.1	EPA 160.1	Total dissolved solids
CLP ILM04.0	CLP ILM04.0	General metals
Standard Methods 4500	Standard Methods 4500	Dissolved oxygen ^a
Standard Methods 2580 B	Standard Methods 2580 B	Redox Potential ^a
EPA 120.1	EPA 120.1	Conductivity ^a
EPA 170.1	EPA 170.1	Temperature ^a
EPA 150.1	EPA 150.1	pH ^a

^a Field measurement

^b Sample preparation and determination of dissolved gases in water using gas chromatography headspace equilibration technique (Kampbell, Wilson, and Vandergrift 1989)

2.5.1 Microwell Groundwater Investigation

As indicated in Table 2-4, 1.5-inch-diameter microwells were installed at 12 of the 26 direct-push soil boring locations during 11–22 June 1998 (see Figure 2-3). Microwells were planned for 15 locations; however, the required depths could not be reached at three locations (at the west end of Waiawa Road) due to obstruction by subsurface debris.

The microwells were installed in accordance with PACDIV IRP Procedure I-C-1, *Monitoring Well Installation*. Each well was constructed of 1.5-inch-outer-diameter, Schedule 80, polyvinyl chloride (PVC) threaded casing with a 5-foot-long, 0.010-inch slotted screen section. The 2-inch-diameter

annular space surrounding the screened interval was backfilled with Number 3 Monterey sand to approximately 2 feet above the top of the screen. The annular space above the sand pack was then backfilled with bentonite chips, which were hydrated during placement. Microwell construction details are shown in Table 2-7 and in the well completion records presented in Appendix D.1.

Table 2-7: Microwell Construction Details

Microwell Number	Top of Casing Elevation (feet above msl)	Total Depth of Well (feet bgs)	Bentonite Seal Interval (feet bgs)	Filter Pack Interval (feet bgs)	Well Screen Interval (feet bgs)
MI-1	9.37	24.5	0.0–15.0	15.0–24.5	19.5–24.5
MI-2	7.36	18.5	0.0–9.0	9.0–18.5	11.5–16.5
MI-3	22.43	25.0	0.0–18.0	18.0–25.0	20.0–25.0
MI-4	15.26	22.0	0.0–15.0	15.0–22.0	17.0–22.0
MI-5	19.77	26.0	0.0–18.0	18.0–26.0	20.0–25.0
MI-6	21.14	25.0	0.0–18.0	18.0–25.0	20.0–25.0
MI-7	20.00	24.0	0.0–17.0	17.0–24.0	19.0–24.0
MI-8	14.15	28.0	0.0–21.0	21.0–28.0	23.0–28.0
MI-9	18.73	24.0	0.0–17.0	17.0–24.0	19.0–24.0
MI-10	15.67	31.0	0.0–24.0	24.0–31.0	26.0–31.0
MI-11	8.35	22.5	0.0–15.5	15.5–22.5	17.5–22.5
MI-12	8.52	14.0	0.0–7.0	7.0–14.0	9.0–14.0

Each microwell was developed in accordance with PACDIV IRP Procedure I-C-2, *Monitoring Well Development*, to enhance the flow of groundwater from the formation into the well and to remove clay, silt, and other fine particles that may interfere with chemical analysis. The microwells were developed during 18–26 June 1998 by using a peristaltic pump to surge and pump each well until three borehole volumes of groundwater were removed. Well development logs are presented in Appendix D.2.

The microwells were purged and sampled during 24–29 June 1998, in accordance with PACDIV IRP Procedure I-C-3, *Monitoring Well Sampling*. Total well depth and water level were measured in each well with an electronic water-level indicator and recorded immediately before purging. To ensure that each groundwater sample was representative of formation water in the vicinity of the microwell, disposable polyethylene bailers were used to remove at least three well volumes of water or bail the well dry before groundwater samples were collected for analysis. Field parameters were measured with the groundwater parameter multiprobe and recorded on groundwater sampling logs (Appendix E). Groundwater for field parameter measurement was immediately transferred directly from the bailers into the measurement chamber of the groundwater parameter multiprobe. Groundwater samples for laboratory analysis were collected with disposable bailers and transferred to laboratory-prepared sample containers. The groundwater samples were then placed on ice in a cooler for transport to the analytical laboratory, where they were analyzed by the methods listed in Table 2-6. Preliminary VOC results for the microwell groundwater samples, provided by the analytical laboratory within 72 hours, were used to select locations for the new monitoring wells in the offsite area. Microwell groundwater sampling results are presented in Section 4.3.

2.5.2 Monitoring Well Groundwater Investigation

Monitoring wells were installed at four locations (see Figure 2-3) in the offsite area during 7–13 July 1998. According to the SAP, a minimum of three and a maximum of seven permanent monitoring wells were to be installed in the offsite area (Earth Tech 1998). Results of the microwell groundwater sampling program indicated that four permanent wells would be sufficient to monitor potential offsite contamination associated with the EJFDF contaminant plume.

Monitoring well components were installed within HSAs in accordance with PACDIV IRP Procedure I-C-1, *Monitoring Well Installation*. The wells, which range between 28.5 and 35 feet in depth, were constructed with 4-inch-diameter Schedule 40 flush-joint threaded PVC casing and 0.020-inch slotted Schedule 40 PVC screen. The filter pack (number 3 sand) was placed with a tremie pipe, and the well was surged to allow the filter pack to settle. Sand was then added to set the top of the filter pack at approximately 2 feet above the top of the screened interval. Approximately 5 feet of bentonite (hydrated with deionized water) was placed immediately above the filter pack with a tremie pipe. The remaining annular space was filled with grout and cement. With the exception of MW-23, which is covered by a flush-mount monument, the wellheads consist of a well monument, concrete pad, and bollards. Monitoring well construction details are shown in Table 2-8 and in the well completion records (see Appendix D.1).

Table 2-8: Monitoring Well Construction Details

Monitoring Well Number	Ground Surface Elevation (feet above msl)	Top of Casing Elevation (feet above msl)	Total Depth of Well (feet bgs)	Grout Interval (feet bgs)	Bentonite Seal Interval (feet bgs)	Filter Pack Interval (feet bgs)	Well Screen Interval (feet bgs)
MW-23	10.96	10.44	28.5	0.0–13.0	13.0–18.5	18.5–28.5	19.5–27.5
MW-24	18.28	20.42	35.0	0.0–19.7	19.7–25.5	25.5–35.0	27.0–35.0
MW-25	23.51	26.34	32.0	0.0–8.0	8.0–13.0	13.0–32.0	15.0–30.0
MW-26	28.07	30.17	30.0	0.0–8.0	8.0–13.0	13.0–30.0	15.0–30.0

Each monitoring well was developed in accordance with PACDIV IRP Procedure I-C-2, *Monitoring Well Development*, to enhance the flow of groundwater from the formation into the well and to remove clay, silt, and other fine particles that may interfere with chemical analysis. The monitoring wells were developed during 10–15 July 1998, by using a submersible pump to surge and pump each well until at least three borehole volumes of groundwater were removed. Well development logs are presented in Appendix D.2.

Groundwater samples were collected from the four new offsite wells and 21 onsite wells in two sampling rounds. Round-one samples were collected during 29 June–17 July 1998. Round-two samples were collected during 29 April–12 May 1999. Each monitoring well was purged and sampled in accordance with PACDIV IRP Procedure No. I-C-2, *Monitoring Well Sampling*. Total well depth and water level were measured with an electronic water-level indicator and recorded immediately before purging. The onsite monitoring wells were purged and sampled with a submersible pump for both sampling rounds. The offsite monitoring wells were purged and sampled with a submersible pump for round one. Dedicated sampling pumps (2-inch diameter, 24-inch length, with Teflon bladder) were installed in the four offsite wells and used for second-round groundwater sampling. To ensure that each groundwater sample was representative of formation water in the vicinity of the monitoring well, groundwater samples were collected after three well volumes of groundwater were removed or field parameters were stable (i.e., successive readings

were within 10 percent of each other). Field parameters were monitored with the multiprobe during purging and recorded on groundwater sampling logs (Appendix E). The multiprobe was equipped with an in-line flow-through chamber to avoid exposing groundwater to the atmosphere prior to field parameter measurement. Groundwater samples for chemical analyses were placed on ice in a cooler for transport to the analytical laboratory, where they were analyzed by the methods listed in Table 2-6. Monitoring well groundwater sampling results are presented in Section 4.3.

2.5.3 Artesian Well Groundwater Investigation

Three of the artesian irrigation wells downgradient of the site (FW-2, FW-3, and FW-5; see Figure 2-3) were sampled on 14 May 1999. As discussed in Section 4.1.2, lead levels above ecological screening criteria were detected in most of the sediment and unfiltered surface water samples collected within the watercress farm area. Elevated lead concentrations were detected in one of the artesian wells sampled during the Phase I RI (FW-3, 15.1 µg/L). Irrigation water from the artesian wells may contribute to the elevated surface water and sediment lead concentrations. The three artesian wells were resampled to investigate the source of the lead. Artesian well sampling was not proposed in the SAP, but was added to the Phase II RI field investigation following a review of round-one sampling results and a teleconference with EPA and DOH (1 April 1999).

The artesian well samples were analyzed for the contaminants listed in Table 2-6, but were not analyzed for hydrogeochemical parameters (sulfate, chloride, nitrate, fluoride, methane, total organic carbon [TOC], and total alkalinity) or surfactants. To evaluate whether lead is associated with suspended particulates, the artesian well samples submitted for metals analysis included one aliquot of filtered groundwater and one unfiltered aliquot.

The water samples were collected by allowing water from each artesian well to flow gently into sample bottles in a manner similar to the method outlined in PACDIV IRP Procedure I-B-4, *Surface Water Sampling*. Each water sample was tested in the field with the multiprobe for dissolved oxygen, redox potential, conductivity, temperature, and pH. Filtered aliquots for lead analysis were obtained by filling a polyethylene pressure bailer with sample water and forcing the water through a 0.45-micron filter with an air pump. Artesian well sampling results are presented in Section 4.3.

2.6 SAMPLE SHIPPING AND HANDLING

All phases of sample collection, handling, and transport were conducted according to Procedures I-A-9, *Sample Naming*; III-E, *Record Keeping, Sample Labeling, and Chain-of-Custody Procedures*; and III-F, *Sample Handling, Storage, and Shipping Procedures*.

2.6.1 Sample Identification Codes

Two identification numbers were assigned to each sample collected during the Phase II RI:

- An EPA identification (ID) number
- A descriptive identifier

The EPA identification number was used by project personnel and the analytical laboratory to track samples and report analytical data. The following format was used for the EPA ID:

VA000

where:

- VA** Identifies the Ewa Junction Phase II RI
- 000** Is a discrete number assigned to each sample

Project personnel used the descriptive identifier. The format of the descriptive identifier is as follows:

M12-A1-D7.0Q

where:

- M12** Refers to the sample type or matrix and number; e.g., monitoring well 12 (refer to Table 2-9)
- A1** Specifies the sample purpose and sample number; e.g., Analytical sample number 1 (the first analytical sample collected from this monitoring well)
- D** Denotes sampling depth
- 7.0** Indicates sampling depth in feet bgs; e.g., 7.0 feet bgs. The depth field contains the date of collection for field blanks or equipment rinsate samples.
- Q** Refers to the field quality control (QC) type, if necessary (refer to Table 2-10)

Table 2-9: Sample Type and Matrix Codes

Identifier	Sample Type	Matrix
B	Subsurface soil	Soil
S	Surface soil	Soil
M	Monitoring well	Groundwater
P	Direct-push	Groundwater
W	Surface water	Water
D	Sediment	Soil

Table 2-10: Field QC Type Designations

Identifier	QC Sample Type	Description
U	Duplicate	Collocated sample
R	Equipment rinsate	Water
F	Field blank	Water
T	Trip blank	Prepared by laboratory

2.6.2 Sample Handling and Labeling

Subsurface soil samples were collected and shipped to the analytical laboratory in stainless-steel sampling sleeves. The sleeve ends were covered with Teflon film and sealed with plastic end caps. Surface soil and sediment samples were collected with stainless-steel hand trowels and placed in glass jars. Samples were placed on ice in a cooler immediately after collection. An adhesive label listing the EPA sample number, date and time of collection, sampler's initials, and analytical requirements was affixed to the side of each sleeve or glass jar. Clear plastic tape was placed over each label for protection. Adhesive custody seals were placed over sleeve end caps and glass jar lids, and each sleeve or jar was individually sealed within a resealable plastic bag. The glass jars were also packed in bubble wrap for protection during shipping. All samples were packed in insulated coolers with frozen gel packs for shipment to the analytical laboratory.

QC samples and water samples were placed in appropriate containers (e.g., 1-liter amber glass bottles for TPH-diesel, 250-milliliter amber glass bottles for TOC, and 1-liter plastic bottles for Contract Laboratory Program [CLP] metals) and preserved, if required. The analytical laboratory provided all sample containers, which were prepared with the required preservatives. The samples were labeled (as described above) and stored on ice in coolers as they were collected. Custody seals were placed around the container lids. Glass containers were enclosed in bubble wrap, and all containers were placed in resealable plastic bags. The samples were shipped to the analytical laboratory in coolers as described above.

2.6.3 Chain of Custody and Shipment

All samples were logged on chain-of-custody (COC) forms prior to shipment to the analytical laboratory. Information recorded on the COC forms included the following:

- EPA sample ID
- Date and time of sample collection
- Depth of sample
- Cooler identification number
- Sample matrix
- Date of sample shipment
- Requested analyses
- Number of containers

Each COC form consisted of three copies; two copies were placed in the appropriate sample-shipping cooler for laboratory use, and the field manager retained the third copy. Copies of the COC forms are provided in Appendix F. COC forms submitted to the laboratory were sealed in resealable plastic bags and taped to the inside of each cooler lid. The coolers were then sealed with duct tape and custody seals were affixed to detect tampering.

Samples remained in continuous field team custody until the sample coolers were turned over to an express shipper for delivery to the analytical laboratory. A copy of the laboratory's soil transport permit was attached to the air bill for soil sample shipments. A copy of the permit was also affixed with clear tape to the outside of each cooler of soil samples. Carbon copies of each air bill were stamped with a United States Department of Agriculture (USDA) stamp prior to shipment. The laboratory received sample coolers within 2 days.

2.7 FIELD QUALITY CONTROL SAMPLING

A total of 107 field QC samples were collected. Field QC samples consisted of 23 equipment rinsate samples, eight field blank samples, 61 trip blank samples, three performance evaluation (PE) samples, and 12 field duplicate samples. All field QC samples were collected in accordance with

PACDIV IRP Procedure III-B, *Field QC Samples (Water, Soil)*. QC sampling results are discussed in Section 4.4.

2.8 TOPOGRAPHIC AND SAMPLING LOCATION SURVEY

Offsite topography and Phase II RI sampling locations were surveyed on 20–21 July 1998 by a land surveyor registered with the State of Hawaii, in accordance with NOAA standards and PACDIV IRP Procedure I-I, *Land Surveying*.¹ Locations of surface features (e.g., roads, ponds, and buildings) and the coordinates of each sampling point were plotted on a comprehensive topographic map. Top-of-casing elevations were plotted for each monitoring well and microwell. The comprehensive map was used to generate the scaled figures presented in this report. Surveyed locations were referenced to local established coordinate systems and adjacent property lines. Horizontal accuracy for planimetric features was ± 0.1 foot, horizontal accuracy for boundaries was one in ten thousand (1:10,000), vertical accuracy for ground surface elevations was ± 0.1 foot, and elevation accuracy for benchmarks and other permanent features was ± 0.01 feet.

2.9 EQUIPMENT DECONTAMINATION

Sampling tools, monitoring instruments, and other equipment used during the field investigation were decontaminated in accordance with PACDIV IRP Procedure I-F, *Equipment Decontamination*. The following five-step decontamination sequence was used:

1. Alconox detergent wash
2. Tap water rinse
3. Isopropyl alcohol spray
4. Distilled water rinse
5. Distilled water spray

2.10 INSTRUMENT CALIBRATION

The PID (used to measure headspace VOC concentrations) and the groundwater parameter multiprobe (used to measure dissolved oxygen, redox potential, conductivity, temperature, pH, and turbidity) were calibrated according to the manufacturers' instructions prior to use in the field.

2.11 INVESTIGATION-DERIVED WASTE MANAGEMENT

IDW generated during the field investigation included the following:

- Personal protective equipment (e.g., Tyvek coveralls and nitrile gloves)
- Disposable sampling equipment and supplies (e.g., bailers, plastic sheeting)
- Water from monitoring well development, purging, and equipment decontamination
- Soil cuttings from the borings

All IDW was handled in accordance with PACDIV IRP Procedure I-A-7, *IDW Management*. The laboratory disposed of soil, sediment, surface water, and groundwater samples submitted for

¹ Onsite topography and sampling locations used during previous investigations were surveyed during the Phase I RI (Ogden 1996).

laboratory analysis. Unused, non-contaminated sample jars and bottles were disposed of as municipal refuse. IDW was sealed in U.S. Department of Transportation-approved 55-gallon drums, transported to an onsite staging area, placed on pallets, and covered with tarps. Fifty-seven drums of IDW were generated. Each drum was labeled with standardized IDW drum labels, marked with indelible paint sticks or pens, and tagged with aluminum identification tags to indicate the contents, date of collection, and other information, as specified in PACDIV IRP Procedure I-A-7. An IDW drum inventory is presented in Appendix G.

3. PHASE II RI PHYSICAL SETTING

The 44-acre EJFDF site is located in an isolated area of the Pearl Harbor Naval Reservation complex, 1.5 miles west of Pearl City, and 1.3 miles east of Waipahu (Figure 1-2). The southern boundary of the site is between 250 and 700 feet from the shore of the Middle Loch of Pearl Harbor. The Phase II RI investigation area includes the EJFDF itself (the onsite area) and the agricultural/wetlands area between the southern site boundary and the shoreline of Middle Loch (the offsite area) (Figure 1-3).

3.1 SITE AND SURROUNDING AREA DEMOGRAPHY AND LAND USE

3.1.1 Demography

The site lies within the Ewa District in the south-central portion of the island of Oahu. Approximately 230,200 persons were living in the Ewa District in 1990. According to 1990 census statistics, the population of the closest town, Waipahu, was 31,435; the population of the next closest town, Pearl City, was 30,993 (Hawaii State Data Center 1991).

3.1.2 Site Land Use

The Navy used the EJFDF site as a fuel drumming and transportation terminal for approximately 30 years. The facility was constructed in 1943 and has been inactive since the early 1970s. The site has been proposed for transfer to the State of Hawaii. Thick vegetation covers much of the site due to the prolonged period of inactivity (approximately 25 years). Structures present at the operating facility included two 585,000-gallon concrete-lined USTs (S-26 and S-27), a fuel drumming facility, and associated piping (Figure 1-3). UST S-26 was used to store MOGAS; UST S-27 contained AVGAS.

According to the DOH, the EJFDF site is scheduled to be transferred to the State Hawaiian Home Lands Department. If the land transfer goes forward, the EJFDF site may be developed for residential purposes in the future. It is important to note, however, that the offsite area between the southern boundary of the EJFDF and Pearl Harbor is private property (not Navy property), and neither transfer nor development is planned.

3.1.3 Surrounding Area Land Use

The EJFDF is bounded by Farrington Highway on the north, Leeward Community College on the east, Waipahu High School on the west, and an agricultural/wetlands area on the south. Within 1 mile of the site are a residential area (to the northeast), a light industrial area (to the north), agricultural lands (to the south and southeast), and a National Wildlife Refuge (to the southeast).

The Phase II RI offsite investigation was concentrated in the agricultural/wetlands (i.e., offsite) area south of the EJFDF. A bicycle path has been constructed along an abandoned railway right-of-way that parallels the Middle Loch shoreline. Much of the land between the EJFDF and the bicycle path has been developed for farming specialty crops, primarily watercress. The fields are flood-irrigated using the output of six artesian wells that tap a deep confined (basal) aquifer at depths of 160 feet or more. The resident population in the agricultural area has been estimated at 20 adults and ten children. Five to ten adults may work in the fields each day. Cultivated areas are interspersed with wetlands, uplands, and drainage ditches. The offsite investigation area is bounded on the west by a recently reconstructed storm water management facility located between Waipahu High School and the bicycle path. An unnamed stream flows along the eastern margin of the offsite investigation area and separates drainage areas on the west (the investigation area) from drainage areas on the east. The source of the stream is the Waiawa Spring and a complex of wells and springs on the Nakatani Farm and areas to the east.

Both the offsite area immediately downgradient of the EJFDF, and the area east of the unnamed stream contain many potential sources of hydrocarbon contamination. These include underground fuel pipelines that cross the area (see discussion in Section 3.6); fill storage piles; abandoned vehicles (e.g., buses); and heavy equipment operations, maintenance, and storage areas (e.g., the Okada Trucking site) (see Figure 3-1).

Three schools are located near the EJFDF: August Ahrens Elementary School, Waipahu High School, and Leeward Community College (LCC). August Ahrens Elementary School is approximately 4,000 feet west-northwest of the site. Waipahu High School is adjacent to the site on the west; high school faculty and students number approximately 130 adults and 1,900 teenagers. LCC is adjacent to the site on the east; approximately 6,600 adults are present at the college when classes are in session. Three areas of light industry, including small shops, offices, warehouses and a shopping plaza, lie within a 1-mile radius of the site.

The Waiawa Unit of the Pearl Harbor National Wildlife Refuge is located approximately 0.35 mile southeast of the site, immediately west of the (now closed) Pearl City Peninsula Landfill. The Waiawa Unit is a constructed freshwater wetland complex operated for the management of four species of endangered water birds. Replacement water for the refuge flows through a closed pipeline system, which is supplied by a freshwater marsh located north of the bicycle path and east of the Nakatani Farm (Figure 3-1). The marsh apparently receives most of its water from artesian sources (Waiawa Spring) east of the Nakatani Farm fields. The water flows by gravity from the marsh through a buried pipe under the bicycle path to a cistern approximately 850 feet west-southwest of the intake (Photo 3-2). The cistern is located at the mouth of the unnamed stream, near the northwest corner of the refuge (see Figure 3-1). Freshwater from the cistern is periodically pumped into the upper pond of the Waiawa Unit.

Water in the unnamed stream at the cistern location is predominantly tidal saltwater. Although a small amount of tidal saltwater from the stream may leak into the cistern, water for the Waiawa Unit is not drawn from the unnamed stream. Therefore, water entering the refuge is freshwater from the marsh east of Nakatani Farm, not saltwater from the unnamed stream.

3.2 CLIMATE AND METEOROLOGY

The mean annual temperature in Honolulu, Hawaii, is approximately 75 degrees Fahrenheit (°F) (24 degrees Celsius [°C]); temperature extremes range from 57° to 90°F (14° to 32°C). The mean daily temperature during the winter is 72°F (22°C); in the hottest summer month (August), it is 79°F (26°C) (NEESA 1983).

The EJFDF area is dry compared to other areas on Oahu. Rainfall varies from approximately 4 inches per month during the winter to 1 inch per month during the summer. Mean annual rainfall is approximately 25.5 inches. Median monthly pan evaporation rates recorded at two stations located just west of the EJFDF indicate that evaporation rates greatly exceed rainfall rates (Ogden 1996).

3.3 BIOLOGICAL RESOURCES

The biological resources of the agricultural/wetlands area downgradient of the site were surveyed in June 1998 during the Phase II RI field investigation.

3.3.1 Vegetation

Table 3-1 lists the vegetation observed at the EJFDF and in the offsite agricultural/wetlands area.



Photo 3-1:
Water intake structure
(grate visible, *bottom*)
for water supply to the
Waiawa Unit of Pearl
Harbor National
Wildlife Refuge. Intake
is adjacent to bicycle
path north of the
Refuge. California grass
and cattails in
foreground; fill
stockpiles in
background.



Photo 3-2: Water accumulation cistern for Waiawa unit of PHNWR. Cistern located in tidal area where the unnamed stream discharges into Pearl Harbor. Freshwater flows into cistern by gravity through 12-inch pipe, *lower right*. Stored water is pumped from cistern into the upper pond of the refuge.

Table 3-1: Vegetation Observed at the EJFDF Site and Adjacent Agricultural/Wetlands Area

Common Name	Latin Name	Habitat
Wetland Vegetation		
Bermuda grass	<i>Cynodon dactylon</i>	SM:F
Barnyard grass	<i>Echinochloa crus-galli</i>	FM, R, C:F
California grass	<i>Brachiaria mutica</i>	FW
Cattail	<i>Typha angustata</i>	SM, FM:OW
Duckweed	<i>Lemna sp.</i>	FA:O
Mangrove	<i>Rhizophora apiculata</i>	SS:O
Milo – Hawaii	<i>Thespesia populnea</i>	SS:F
Parrot's feather	<i>Myriophyllum brasiliense</i>	FA:OW
Pickle weed	<i>Batis maritima</i>	SM:F
Sourbush	<i>Pluchea indica</i>	SM
Swamp morning glory	<i>Ipomea aquatica</i>	R, C
Taro	<i>Colocasia esculenta</i>	C
Torpedo grass	<i>Panicum repens</i>	FM, SM
Water fern	<i>Azolla filiculoides</i>	FA:O
Water lily	<i>Nymphaea sp.</i>	FA
Watercress	<i>Nasturtium microphyllum</i>	FA, C
Upland Vegetation		
Buffel grass	<i>Cenchrus ciliaris</i>	U
Bermuda grass	<i>Cynodon dactylon</i>	FU
Castor bean	<i>Ricinus communis</i>	FU
Chinese violet	<i>Asystasia gangetica</i>	U
Coat buttons	<i>Tridax procumbens</i>	U
Golden crown-beard	<i>Verbesina encelioides</i>	U
Guinea grass	<i>Panicum maximum</i>	FU
Kiawe	<i>Prosopis pallida</i>	FU
Mexican creeper	<i>Antigonon leptopus</i>	U
None	<i>Crassocephalum crepidioides</i>	F
None	<i>Pycnus polystachyos</i>	F
Partridge pea	<i>Chamaecrista nictitans</i>	U
Shrub koa haole	<i>Leucaena leucocephala</i>	U
Sourgrass	<i>Digitaria insularis</i>	FU
Swollen fingergrass	<i>Chloris barbata</i>	FU
'Uhaloa	<i>Waltheria indica</i>	U

Habitat codes:

C = cultivated wetlands
 FM = freshwater marsh
 FW = facultative wetland plant
 SS = saltwater swamp

F = facultative plant
 FS = freshwater swamp
 R = ruderal
 U = upland plant

FA = freshwater aquatic
 FU = facultative upland plant
 SM = saltwater marsh

No plant species listed as rare, threatened, or endangered have been observed during surveys of the EJFDF and offsite area. Furthermore, due to the disturbed conditions, no listed species are expected to exist in the investigation area (USFWS 1991).

Onsite Vegetation. The EJFDF was cleared of native vegetation in the past, allowing species foreign to the Hawaiian Islands to become dominant (Ogden 1996). The site supports a vegetation community described as coastal dry koa haole shrubland with dry mixed vegetation. Impenetrable thickets of the invasive shrub koa haole (*Leucaena leucocephala*) cover most of the site, except along old access roads and in the primary facilities areas. The principle scrub understory species is California grass (*Brachiaria mutica*). Tree kiawe (*Prosopis pallida*) occurs at higher elevations near the UST locations and along the upper edge of the steep slope near the southern boundary of the site. Areas along the dirt access roads and around the main fuel drumming facilities are dominated by California grass, swollen fingergrass (*Chloris barbata*), sourgrass (*Digitaria insularis*), partridge pea (*Chamaecrista nictitans*), Chinese violet (*Asystasia gangetica*), 'uhaloa (*Waltheria indica*), golden crown-beard (*Verbesina encelioides*), and Mexican creeper (*Antigonon leptopus*). The plant communities observed at the EJFDF during the Phase II RI field investigation in 1998 and 1999 were the same as those described in the Phase I RI report (Ogden 1996); however, the communities were more mature during the Phase II investigation.

Offsite Vegetation. The ecological survey for the 1998 Phase II RI concentrated on the agricultural/wetlands complex downgradient of the EJFDF. The following offsite plant communities were identified during the survey:

Coastal Dry Koa Haole Shrub. An upland area directly south of the EJFDF site, between the renovated stormwater management pond and the Sasaki Farm, has developed a vegetative community similar to that found on the EJFDF site. Small portions of this area have been cleared for upland farming (Photo 3-3). The southern part of the wetland on the Sasaki Farm, adjacent to the bicycle path, has recently been filled and graded, and the outfall ditch has been rerouted.

Disturbed Emergent Wetland. The former marshland and adjacent uplands have been dramatically altered by excavation of ponds and drainage ditches and construction of flooded watercress fields and filling (Photo 3-4 and Photo 3-5). The ponds have developed a flora of aquatic vegetation such as cattails (*Typha angustata*), parrot's feather (*Myriophyllum brasiliense*), water lilies (*Nymphaea* sp.), duckweed (*Lemna* sp.), and water fern (*Azolla filiculoides*). The dominant vegetation in the wetlands and former wetlands is a thick stand of torpedo grass (*Panicum repens*), Bermuda grass (*Cynodon dactylon*), and California grass (*Brachiaria mutica*), with scattered stands of sourbush (*Pluchea indica*).

Littoral Mangrove Swamp. The shore of Middle Loch in the western part of the investigation area is a small gravel beach with scattered littoral vegetation, dominated by mangrove (*Rhizophora apiculata*) in the zone of normal tidal influence; milo (*Thespesia populnea*) at elevations above the mangroves, in areas influenced by the highest tides; and sourbush at elevations just above the milo. The mangrove swamp community is confined to the littoral area south of the bicycle path.

Agricultural Wetlands. The agricultural wetlands have been developed in natural wetlands and by excavating areas formerly occupied by natural wetlands. Local farmers indicate that agricultural development of the wetland complex began at least 100 years ago, with the channeling of the outflow of the Waiawa Spring (Photo 3-6) to irrigate rice. During the 1950s, artesian wells were drilled to provide water to individual farms. Higher value crops such as taro (*Colocasia esculenta*) and watercress (*Nasturtium microphyllum*) replaced rice as the primary crop when inexpensive rice became available from California.



Photo 3-3: Upland farm area downgradient from EJFDF, which is located beyond power poles in the background.



Photo 3-4: View toward northeast from bicycle path bridge over unnamed stream. Stream in foreground. Fill material, heavy equipment storage, and Nakatani watercress farm in the distance.



Photo 3-5: View toward southwest from Okada Trucking Co. property. Excavation of ponds and stockpiles of fill in the foreground. Dense mangrove swamp in distance is located between the bicycle path and the National Wildlife Refuge.



Photo 3-6: Waiawa Spring, located on the Nakatani Farm. This spring (and wells) supply flowing water to the watercress beds and the unnamed stream that discharges into Pearl Harbor.

Currently, the major crop is watercress, which is grown in leveled, diked paddies. A constant flow of water is supplied to the fields by the artesian wells. The artesian water is slightly brackish, and the watercress farmers have found that the salt content has been increasing. One of the farmers (Mr. Sasaki) has recently switched to a more salt-tolerant variety of watercress. The fields are also irrigated with sprinklers to help control pests and reduce the need for pesticides. The sprinklers are activated automatically for about 10 minutes every hour or two.

The outflow of irrigation water from the Sasaki Farm is collected in a ditch that discharges through a culvert under the bicycle path into Pearl Harbor. The outflow of irrigation water from the Oshita Farm is collected in a tidal ditch that flows eastward to the unnamed stream originating on the Nakatani Farm (Photo 3-7 and Photo 3-8). The unnamed tidal stream then flows to Pearl Harbor (Photo 3-4). The salinity of the ditch and unnamed stream vary as a function of the (saltwater) tidal flow from the harbor and the (freshwater) irrigation flow.

Ruderal Plant Community. Several areas have been cleared for roadways, farmyards, general access, and storage of heavy equipment and fill. A mixture of early successional grasses and weedy species have invaded these sites to varying degrees. Ornamental trees and shrubs are planted near both occupied and unoccupied residences.

3.3.2 Wildlife

The Phase I RI report notes that no rare, threatened, or endangered animal species were observed on site at the EJFDF during surveys in 1991, and that none are expected due to the extensive non-native vegetation. However, endangered water birds were observed in the offsite agricultural/wetlands area during the 1998 ecological survey.

3.3.2.1 ONSITE WILDLIFE

Birds. Twelve bird species were observed on the EJFDF site during the 1991 survey. The most abundant species included zebra dove (*Geopelia striata*), spotted dove (*Streptopelia chinensis*), red-vented bulbul (*Pycnonotus cafer*), common waxbill (*Estrilda astrild*), and chestnut mannikin (*Lonchura malacca*).

Mammals. Mammal populations were not assessed by onsite surveys; however, according to the Phase I RI report, species expected to inhabit the EJFDF site include the black rat (*Rattus rattus*), house mouse (*Mus musculus*), and Indian mongoose (*Herpestes auropunctatus*) (Ogden 1996).

3.3.2.2 OFFSITE WILDLIFE

Birds. The offsite agricultural/wetlands area may be used by endangered water birds, including the Hawaiian coot (*Fulica americana alai*), Hawaiian common moorhen (*Gallinula chloropus sandvicensis*), and Hawaiian duck (*Anas wyvilliana*). The Hawaiian black-necked stilt (*Himantopus mexicanus knudseni*) was observed foraging in the watercress fields and may forage along the shoreline south of the EJFDF. The bird species observed on site are also common in the agricultural/wetlands area.

Local farmers indicate that Hawaiian coots were relatively common in the offsite area several decades ago, when the major crops were taro and lotus. The coots foraged in the open space under the large leaves. However, coots were rarely observed after watercress became the dominant crop. Black-necked stilts and cattle egrets are commonly observed foraging in the watercress fields. The farmers do not report seeing the Hawaiian duck, but the Hawaiian common moorhen is seen occasionally. The farmers also reported occasionally seeing short-eared owls (*Asio flammeus*

sandwichensis) using the area in the evenings. Table 3-2 lists bird species that have been observed at the EJFDF or in the offsite agricultural/wetlands area.

Table 3-2: Bird Species in the EJFDF Phase II RI Investigation Area

Common Name	Latin Name
Black-crowned night-heron	<i>Nycticorax nycticorax hoactli</i>
Cattle egret	<i>Bubulcus ibis</i>
Chestnut mannikin	<i>Lonchura malacca</i>
Common mynah	<i>Acridotheres tristis</i>
Common waxbill	<i>Estrilda astrild</i>
Hawaiian black-necked stilt	<i>Himantopus mexicanus knudseni</i>
Hawaiian common moorhen*	<i>Gallinula chloropus sandvicensis</i>
Hawaiian coot*	<i>Fulica americana alai</i>
House finch	<i>Carpodacus mexicanus</i>
House sparrow	<i>Passer domesticus</i>
Java sparrow	<i>Padda oryzivora</i>
Northern cardinal	<i>Cardinalis cardinalis</i>
Red-crested cardinal	<i>Paroaria coronata</i>
Red-vented bulbul	<i>Pycnonotus cafer</i>
Short-eared owl*	<i>Asio flammeus sandwichensis</i>
Spotted dove	<i>Streptopelia chinensis</i>
Zebra dove	<i>Geopelia striata</i>

* Verbal reports from farmers; commonly observed in past years.

Mammals. The only mammals directly observed during the 1998 offsite survey were the Indian mongoose (*Herpestes auropunctatus*), and domestic dog (*Canis familiaris*). Evidence of the house cat (*Felis domesticus*), Norwegian rat (*Rattus norvegicus*), and house mouse (*Mus musculus*) was also noted.

Amphibians and Reptiles. The amphibians and reptiles listed in Table 3-3 have been observed in the offsite agricultural/wetlands area.

Table 3-3: Amphibians and Reptiles Observed in the Agricultural/Wetlands Area

Common Name	Latin Name
Cane toad	<i>Bufo marinus</i>
Bullfrog	<i>Rana catesbiana</i>
Garden skink	<i>Lampropholis delicata</i>
House gecko	<i>Hemidactylus frenatus</i>
Green anole lizard	<i>Anolis carolinensis porcatus</i>



Photo 3-7: View toward east along tidal drainage ditch that parallels the bicycle path (path follows power line, *right*). Excess flowing water from the Oshita watercress beds flows over riffle into drainage ditch.



Photo 3-8: View toward north along Oshita watercress beds. Water flows from artesian well, *distant right*, through fields, and over stone weir into tidal drainage ditch. EJFDF parcel occupies the hillside beyond the abandoned farm house. Leeward Community College, *upper right*.

3.4 TOPOGRAPHY

As shown in Figure 3-2, the elevation of the Phase II RI investigation area ranges from sea level along the shore of Middle Loch to approximately 100 feet above msl at the northern boundary of the EJFDF. The elevation along the EJFDF southern boundary fence is approximately 30 feet above msl, and along Waiawa Road (just south of the fence) it is approximately 25 feet above msl. Drainage is generally directed toward the southern portion of the EJFDF, where a deep gully has developed. Due to the lack of activity in recent years, the EJFDF site is almost completely overgrown with dense vegetation.

Waiawa Road separates the EJFDF site from the offsite investigation area. An embankment slopes down from Waiawa Road to the watercress farm area, which generally ranges between 5 and 15 feet above msl. The lowest portions of the offsite area are near sea level along the shoreline; therefore, the lower drainage channels experience the ebb and flow of the tide from Middle Loch.

3.5 SURFACE WATER HYDROLOGY

Surface water generally drains from north to south at the EJFDF and concentrates in the extreme south-central portion of the site, where the deep gully has developed. The major surface water drainage feature in the offsite area is the unnamed stream that originates on the Nakatani Farm and drains much of the agricultural land southeast of the EJFDF site. The surface water hydrology of the offsite agricultural/wetlands area was surveyed in June 1998 as part of the Phase II RI field investigation. Offsite surface water drainage is shown in Figure 3-3.

Irrigation and drinking water for the agricultural area is provided by artesian wells that tap a deep confined (basal) aquifer at depths of 160 feet bgs or more. Six artesian (flowing wells) were identified in the offsite area during the Phase I RI. The six wells are listed in the State of Hawaii Groundwater Index and Summary, Department of Land and Natural Resources (DLNR 1998). The wells are designated 2359-05 (FW-1), 2359-06 (FW-5), 2359-07 (FW-3), 2359-15 (FW-6), 2359-16 (FW-4), and 2359-17 (FW-2). The index identifies FW-5 and FW-6 as unused; however, FW-5, which provides irrigation water for the Sasaki watercress patch, was in use at the time of the Phase II RI round two sampling effort in 1999. The artesian flow is very abundant; however, seasonal fluctuations are evident. With the approach of summer, flow is decreased and the water becomes saltier. Watercress is the primary crop irrigated by water from the flowing wells. The typical watercress field is excavated to the desired depth (average 1–2 feet below grade), filled with a few inches of gravel, and then flooded to a depth of 3–4 inches. The water is allowed to flow naturally; the excess is channeled down into tidal ditches that drain into the Middle Loch of Pearl Harbor (Photo 3-7 and Photo 3-8). The watercress farm area extends from the Sasaki farm on the west to the marsh complex east of the Nakatani farm. A recently reconstructed stormwater management facility between Waipahu High School and the bicycle path bounds the offsite investigation area on the west.

The unnamed stream that originates on the Nakatani Farm (Photo 3-6) flows along the eastern margin of the offsite investigation area. The Nakatani farm is located east of the stream and is not included in the investigation area because it is in a different watershed from that of the EJFDF, the Oshita Farm, and the Sasaki Farm. With the exception of the Sasaki Farm area, the unnamed stream drains the entire agricultural wetland area south of the site, as well as the extensive agricultural and wetland area east of the stream (which includes the Nakatani Farm). Surface water and sediment samples collected at the mouth of the unnamed stream would therefore be subject to contamination from a variety of sources. The drainage areas on both sides of the unnamed stream contain numerous potential sources of hydrocarbon contamination (see Section 3.1.3).

The paved bicycle path south of the watercress farm area separates the hydrology of the offsite area into a freshwater zone and tidal drainage ditch north of the path and a marine estuary (Middle Loch) south of the path. Most of the freshwater agricultural drainage and runoff from the EJFDF crosses beneath the bicycle path at four points (see Figure 3-1):

- Under the bicycle path bridge (Photo 3-4), which spans the unnamed stream that receives drainage from as far west as the Oshita farm and as far east as a marsh east of the Nakatani Farm. The marsh is the source of freshwater for the Waiawa Unit of the Pearl Harbor National Wildlife Refuge (Figure 3-1).
- Through a 10-inch metal pipe that drains the Sasaki Farm to the mangrove swamp along the shoreline
- Through two culverts and outfall control structures that drain the stormwater management pond south of Waipahu High School

The four outfalls are at elevations susceptible to tidal influence.

3.6 UNDERGROUND UTILITIES

A map of onsite underground utilities appears in the Phase I RI report (Ogden 1996). This section focuses on the underground pipelines in the offsite area south of the EJFDF shown in Figure 3-3.

Petroleum product pipelines exist both north and south of the offsite agricultural area and must be considered potential sources of contamination. A 10-inch-diameter petroleum product pipeline operated by Tesoro (formerly operated by BHP Hawaii) parallels the southern boundary of the EJFDF just inside the fenceline, along an easement corridor through Navy property. The pipeline runs from Campbell Industrial Park in southwest Oahu into downtown Honolulu, and has been in operation since the early 1970s. The pipeline carries gasoline, diesel fuel, or kerosene (at different times).

At least three petroleum product pipelines are known to parallel the bicycle path between the agricultural area and the shore of Middle Loch. A 10-inch-diameter pipeline operated by Navy FISC carries JP-5 jet fuel. The pipeline runs along the south side of the bicycle path, but crosses beneath the path near west end of the offsite area and continues west along the north side of the path. Chevron operates two 8-inch-diameter petroleum product pipelines that run along the north side of the bicycle path. One of the pipelines, the "black oil" line, carries fuel oil; the other pipeline, the "white oil" line, carries jet fuel, diesel fuel, or gasoline (at different times). Chevron formerly operated a 4-inch "tracer" pipeline (also along the north side of the bicycle path) that carried hot water, but is now inactive. During the utility clearance survey conducted for the Phase II RI field investigation, another pipeline or section of a pipeline was identified near the west end of the offsite area, north of the FISC pipeline. The operator of this pipeline and the type of material transported (if any) have not been determined. A force-main sanitary sewer parallels the FISC petroleum pipeline south of the bicycle path.

A 10-inch sanitary sewer main runs southwest to northeast through the offsite area, south of and roughly parallel to Waiawa Road. In August 1995, workers excavating a trench for installation of the sewer main reportedly observed a "petroleum-based contaminant" in excavated soil (Okada 1995). The petroleum contamination was reportedly observed only in the area between the Oshita watercress patch and the farmhouse to the north.

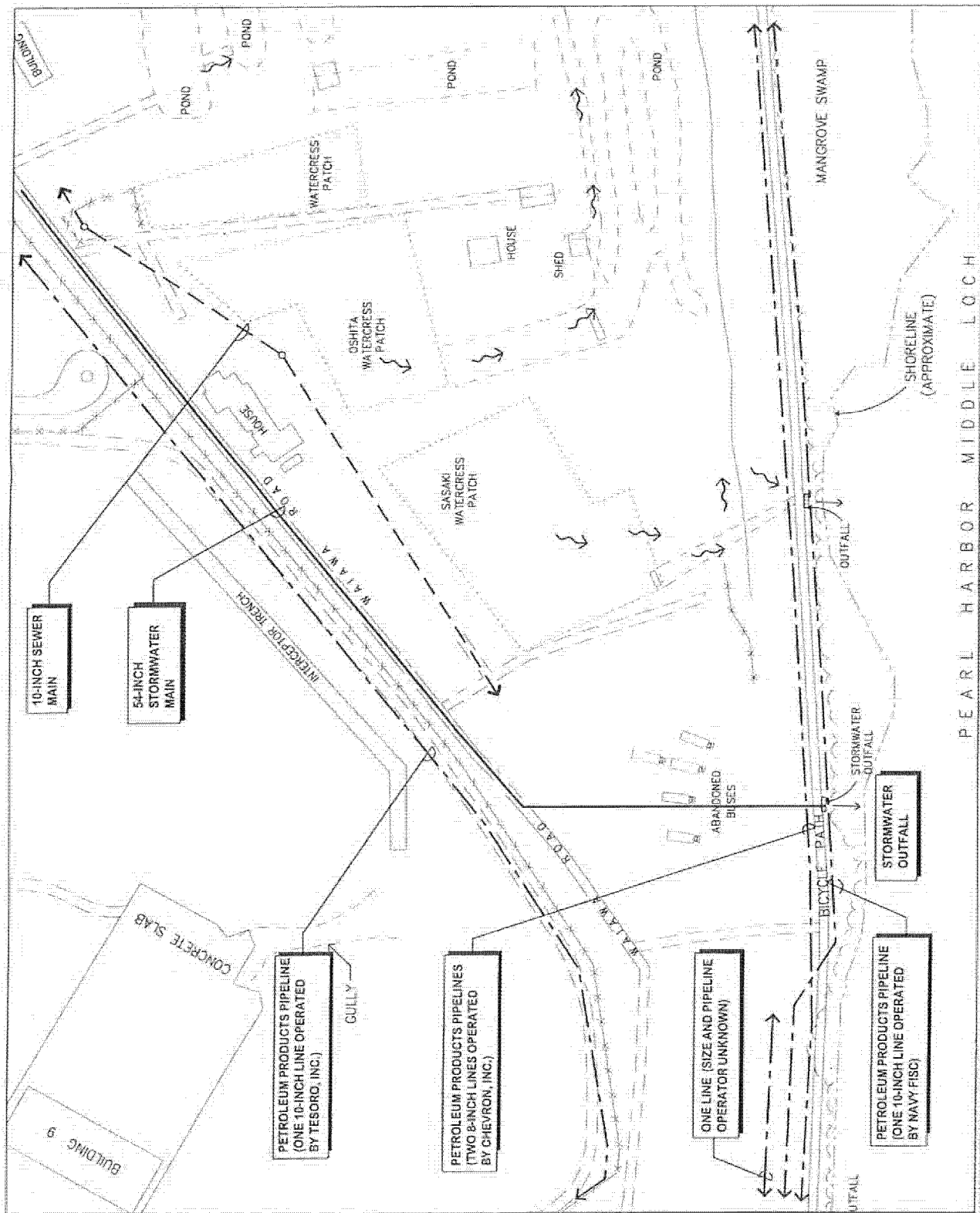


Figure 3-3
Offsite Surface Water Drainage
and Underground Utilities
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii

A 54-inch concrete-reinforced stormwater pipe from LCC discharges to Middle Loch at a point south of the abandoned buses. The storm drain conveys storm runoff from LCC southwest along Waiawa Road, parallel to the southern boundary of the EJFDF, to the west side of the Sasaki farm, where it turns south to the Middle Loch outfall. The backfilled trench of the storm drain may serve as a migration pathway for caprock groundwater to the Middle Loch outfall.

3.7 REGIONAL GEOLOGIC SETTING

Two major volcanic mountain ranges form the island of Oahu. Both ranges are the eroded remnants of large elongate shield volcanoes. The Koolau Range on the east is much younger than the Waianae Range on the west. The gently sloping plain (Schofield Plateau) that separates the two ranges was formed when Koolau lava flows banked against the eroded slopes of the Waianae Range. After a long period of erosion, volcanic activity resumed with the eruption of the vents and lava flows of the Honolulu Volcanic Series. The lava flows on Oahu, as on all of the Hawaiian Islands, are basaltic in composition. Individual flows are generally thin and extremely permeable.

The EJFDF is located south of the Schofield Plateau on the Ewa Plain, a large lowland coastal plain formed by interbedded alluvial and marine deposits. The coastal plain deposits, or "caprock," include sand, gravel, and low-permeability beds of clay and silt. The low-permeability caprock strata may form confining layers above a basal aquifer (the Pearl Harbor Aquifer) that exists within the underlying highly permeable fractured Koolau basalts. The caprock strata may contain unconfined near-surface groundwater (caprock water-bearing zones). Regional geology is depicted in Figure 3-4.

3.7.1 Investigation Area Geology

Onsite Geology. The Phase I RI report presents a detailed description of the geology of the onsite area, as interpreted from the logs of approximately 25 onsite borings advanced during the Phase I RI and previous investigations (Ogden 1996). As summarized in the report, the subsurface at the EJFDF consists of relatively impermeable interbedded alluvial and marine deposits (caprock) overlying highly permeable fractured Koolau basalts. The sedimentary deposits are up to 95 feet thick in the northern portion of the site, and decrease in thickness as the ground surface slopes down toward the shore of Middle Loch. The sediments are approximately 35 feet thick along the southern boundary of the EJFDF.

Silts, clayey silts, and silty clays overlie the unconfined caprock water-bearing zone in the onsite area. The caprock water-bearing zone occurs within silty sand and silty gravels interbedded with silts, clayey silts, and silty clays. Sand or gravel was encountered at the water table in most of the onsite borings.

The confined basal aquifer exists within the basalts that underlie the caprock. Driller's logs from the artesian wells in the agricultural area downgradient of the site indicate that the confined basal aquifer was encountered at a depth of approximately 45–58 feet bgs (40–50 feet below msl) (Ogden 1996). Therefore, in the onsite area, the confined basal aquifer would be encountered at approximately 75 feet bgs near the southern boundary of the site, and at approximately 135 feet bgs near the northern boundary of the site.

Boring logs were used to construct geologic cross sections along transects that intersect borings completed during the Phase II RI, Phase I RI, and previous investigations. The cross sections group the various stratigraphic units described on the boring logs into broad classifications (i.e., gravel,

sand, silty clay, and weathered basalt) to facilitate visualization of the subsurface. The cross sections are presented in Figure 3-5, Figure 3-6, Figure 3-7, and Figure 3-8.

Offsite Geology. This section provides an overview of the geology of the agricultural/wetlands area between the EJFDF southern boundary and the Middle Loch shoreline, as interpreted from the boring logs of 26 direct-push and four HSA borings completed in the offsite area during the Phase II RI. The borings were advanced to investigate the downgradient extent of soil and groundwater contamination associated with the EJFDF MOGAS release. Boring locations are shown in Figure 2-3; boring logs are presented in Appendix C.

The thickness of the sedimentary sequence in the offsite area is much less than in the onsite area. The decrease in thickness is associated with the low elevation of the offsite area, combined with an increase in the elevation of the underlying basalt bedrock. Offsite strata are predominantly stiff silty clays. The relatively permeable sediments that occur within the caprock water-bearing zone on site (the silty sand, silty gravel, and sandy gravel units) tend to pinch out downgradient of the EJFDF. Therefore, the offsite strata are generally less permeable than the onsite strata. Caprock groundwater in the offsite area occurs within thin silty sand and silty gravel layers interbedded with the silty clays, and may also occur within the underlying weathered basalt. Offsite geology is illustrated in the geologic cross sections presented in Figure 3-5, Figure 3-6, Figure 3-7, and Figure 3-8.

3.8 HYDROGEOLOGY

3.8.1 Regional Hydrogeology

The hydrogeologic characteristics of the EJFDF area are very common in the Hawaiian Islands. Two distinct groundwater bodies occur in the site area:

- An unconfined, near-surface water-bearing zone (the caprock groundwater)
- A deep confined aquifer, commonly referred to as a basal aquifer. The general hydrogeology of the EJFDF region is shown in Figure 3-4.

The confined basal aquifer that underlies the EJFDF is part of the Pearl Harbor Aquifer, the most productive aquifer in the State of Hawaii. Fresh water of the confined basal aquifer floats on and displaces salt water, which saturates the highly permeable basalts at the base of the island of Oahu. Basal groundwater in the EJFDF area originates as rainwater in higher drainage basins to the north and northeast. The basal groundwater generally migrates seaward through zones of highly permeable, fractured basalt, and flows beneath relatively impermeable sedimentary confining layers (caprock) as it approaches Pearl Harbor. The Pearl Harbor Aquifer has been thoroughly investigated (Wentworth 1951; Mink 1980; Mink, Yuen, and Chang 1988). Horizontal hydraulic conductivities of the fractured basalts of the Pearl Harbor Aquifer range from approximately 9×10^{-2} centimeter per second (cm/sec) to 7×10^{-1} cm/sec. The potentiometric surface of the confined basal aquifer slopes gently toward the shore of Pearl Harbor; the hydraulic gradient is approximately 0.3 meter per kilometer (m/km).

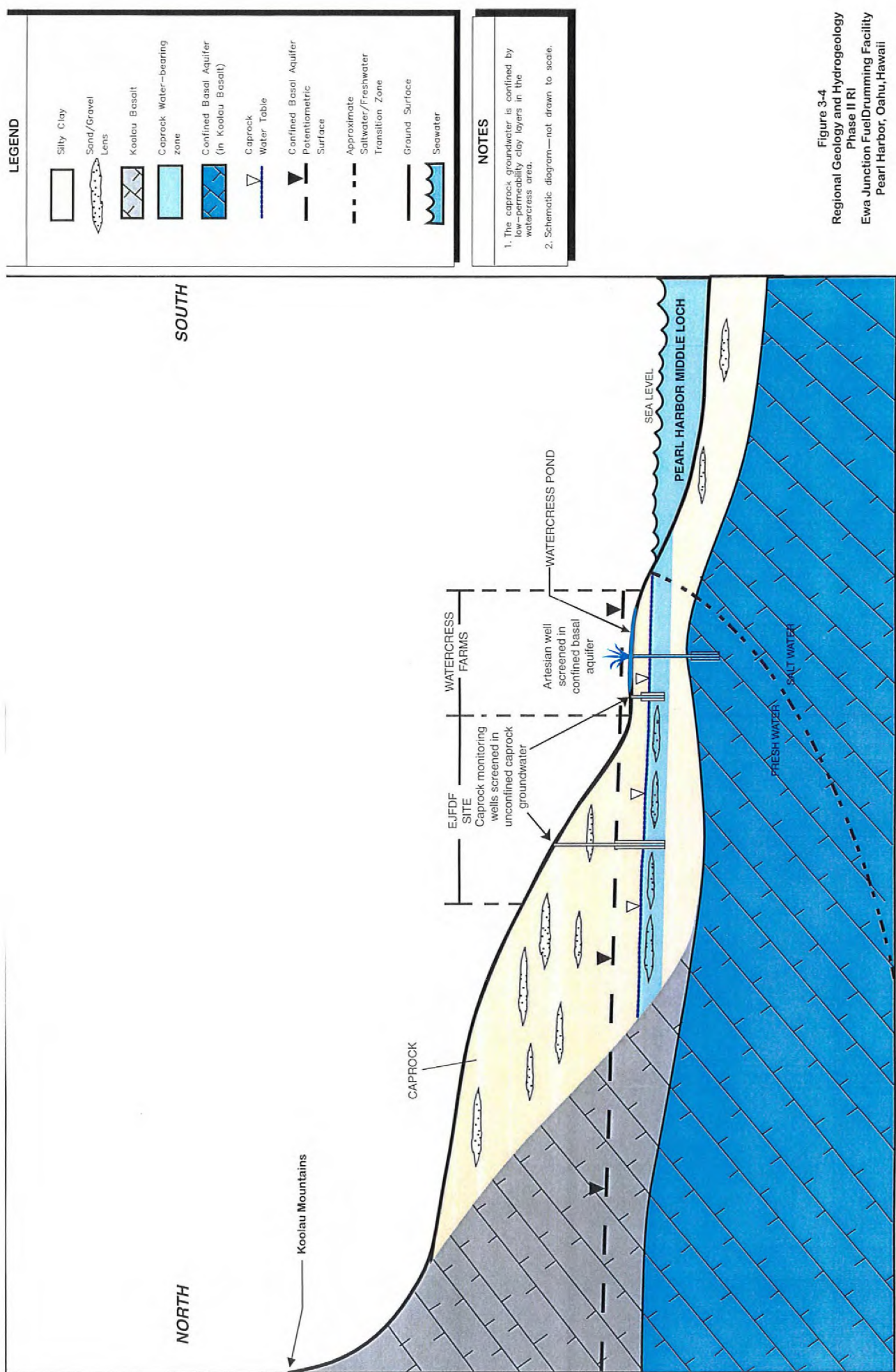


Figure 3-4
Regional Geology and Hydrogeology
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

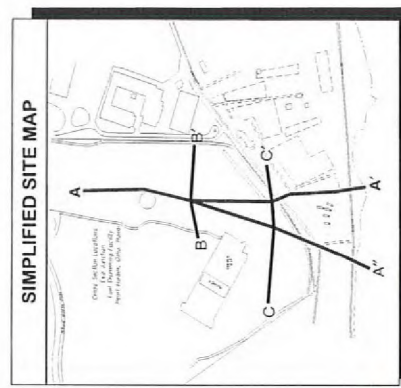
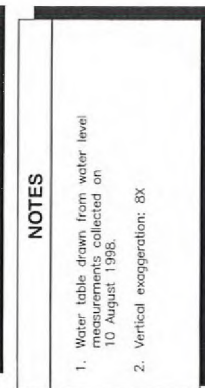
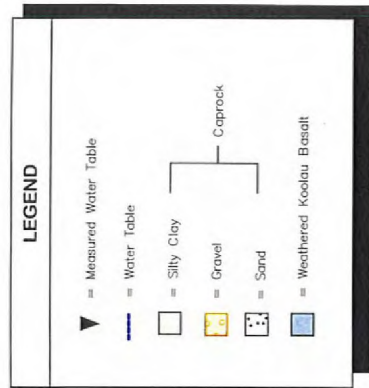
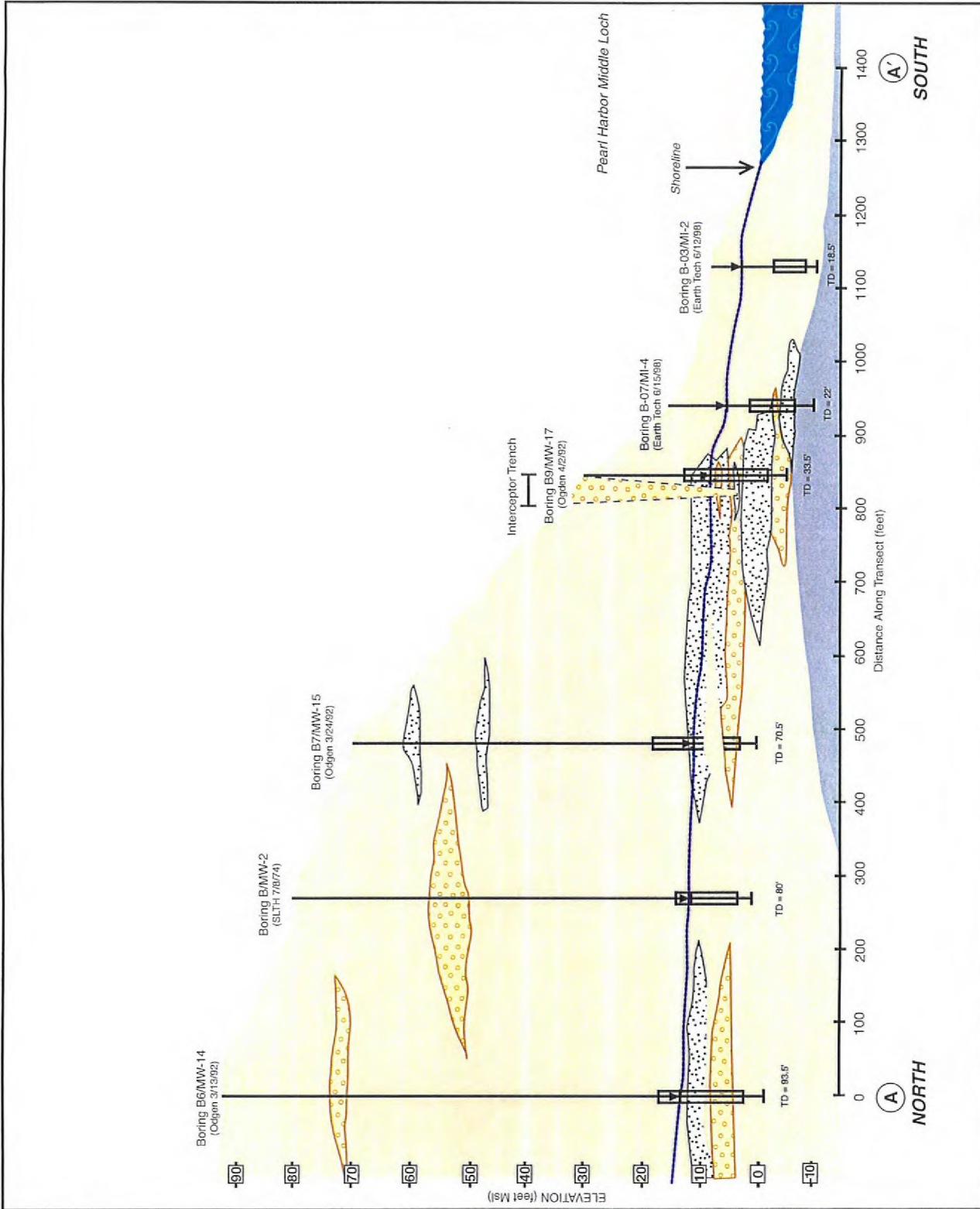
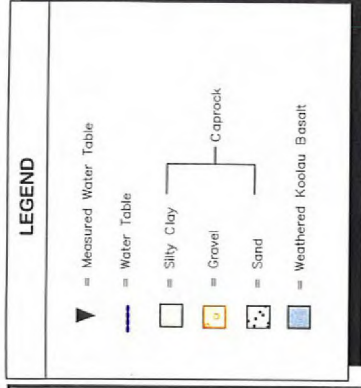


Figure 3-5
Geologic Cross Section A-A'
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



U.S. GEOLOGICAL SURVEY, PACIFIC DIVISION, OFFICE OF WATER RESOURCES, PEARL HARBOR, OAHU, HAWAII



NOTES

- Water table drawn from water level instrument collected on 10 August 1998. At MW-4, water level was 10 feet from MW-4; however, because the boring log was not available, lithology and elevation data are from Boring 1 (SLTH 1975).
- Vertical exaggeration: 8X

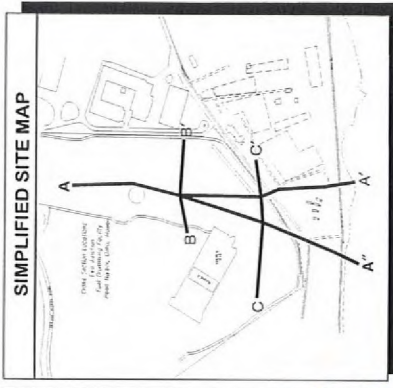
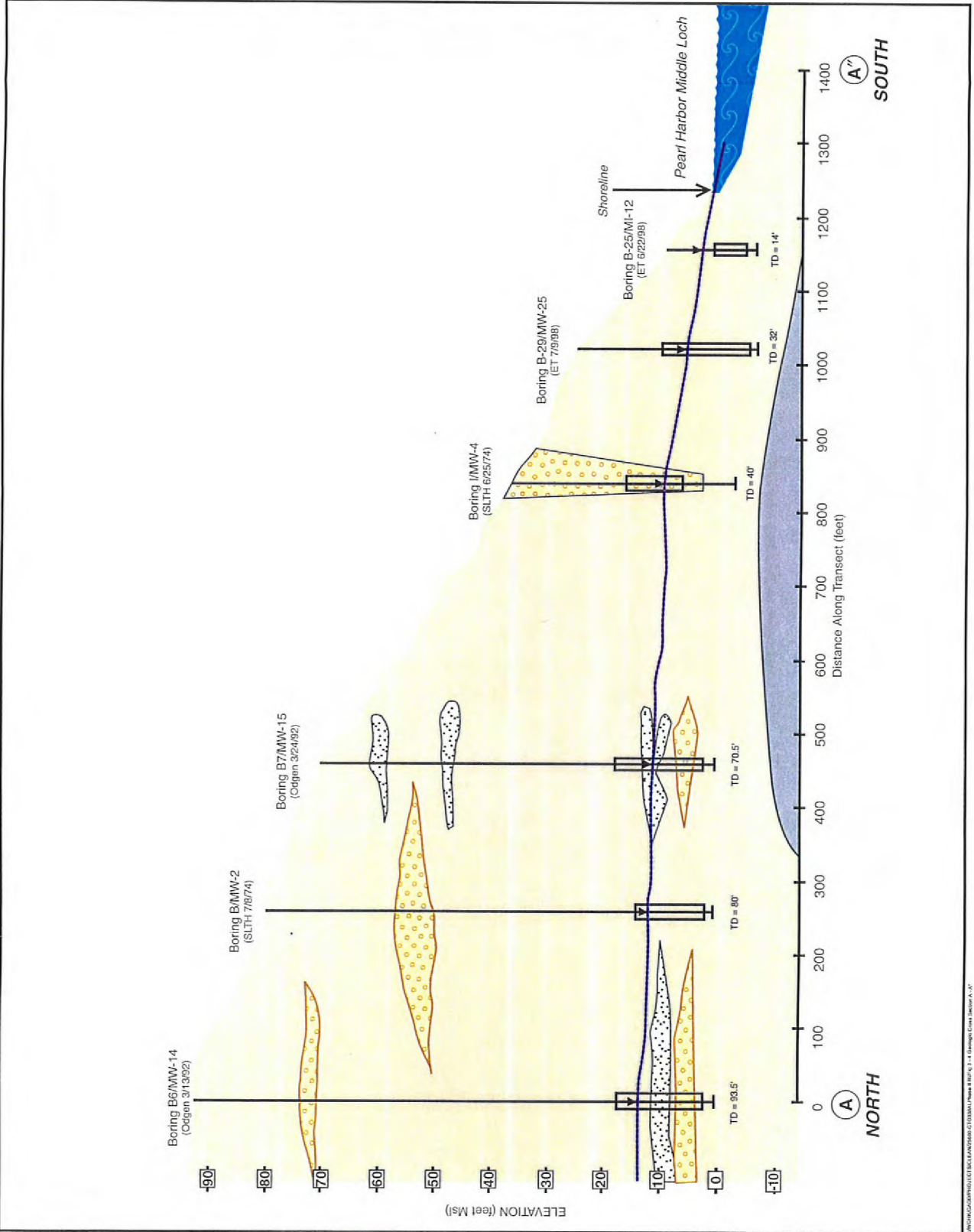


Figure 3-6
Geologic Cross Section A-A'
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii



LEGEND

- Measured Water Table
- Water Table
- Silty Clay
- Gravel
- Sand
- Caprock
- Weathered Koalaui Basalt

NOTES

- Water table drawn from water level measured collected on 10 August 1998. At MW-10, well construction details are from MW-10; however, because the boring log was not available, lithology and elevation data are from Boring F (SLTH 1975).
- Vertical exaggeration: 8X

SIMPLIFIED SITE MAP

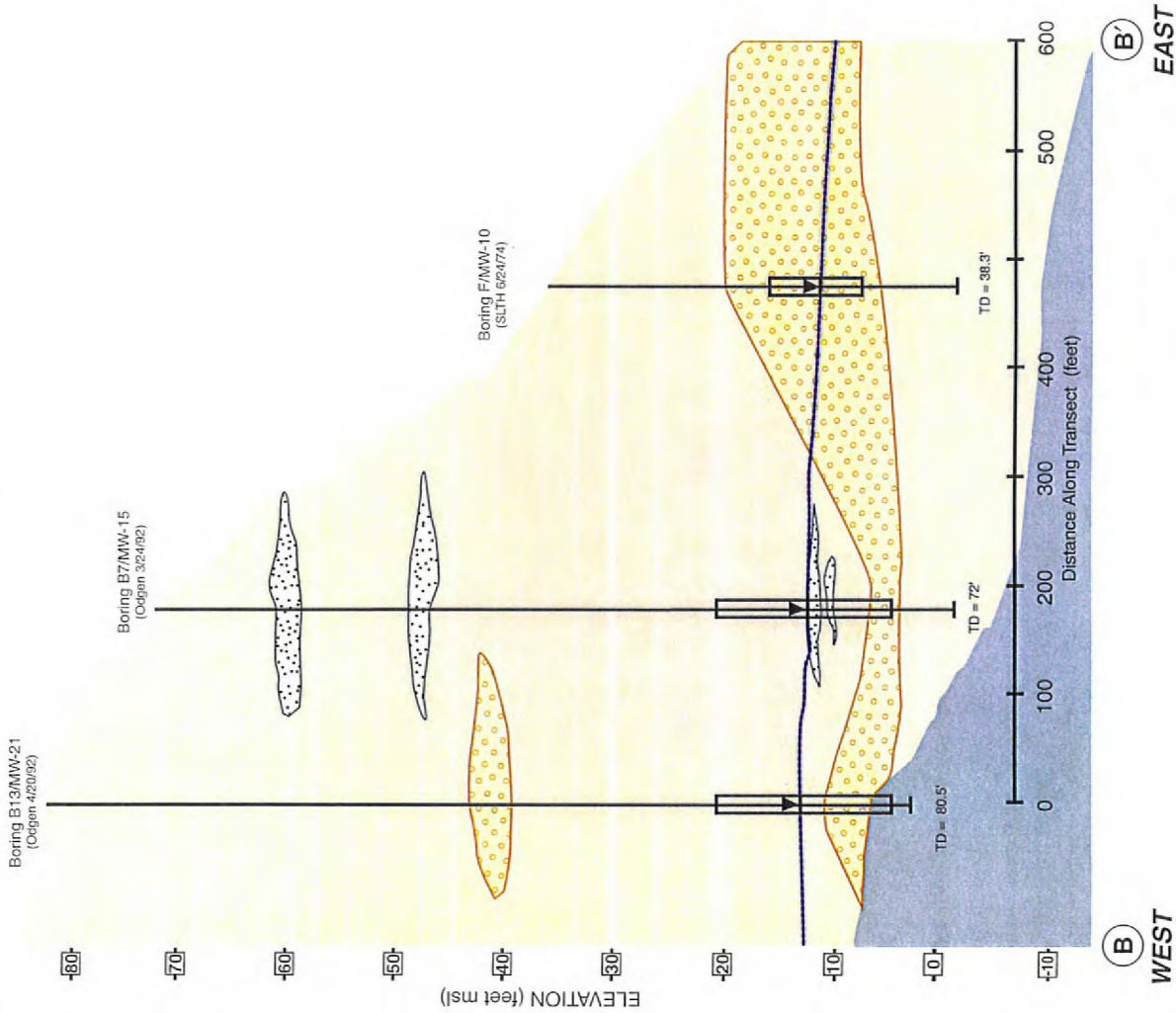
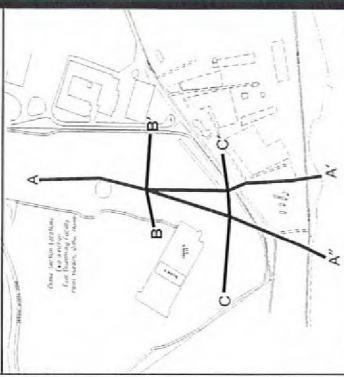


Figure 3-7
Geologic Cross Section B-B'
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

LEGEND

- Measured Water Table
- Water Table
- Silty Clay
- Gravel
- Sand
- Caprock
- Weathered Koolau Basalt

NOTES

- Water table drawn from water level measurements collected on 10 August 1995. At MW-4, water construction details are from MW-4; however, the construction details for the dog-leg are not available. Lithology and elevation data are from Boring I (SLTH 1975).
- Vertical exaggeration: 8X
- Due to dog-leg in trench, this cross section intersects in two places.

SIMPLIFIED SITE MAP

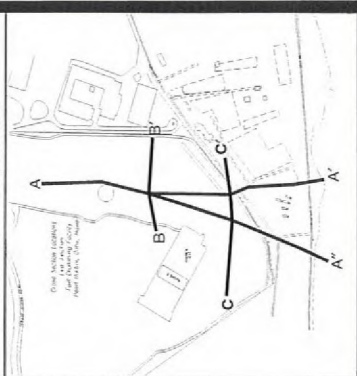
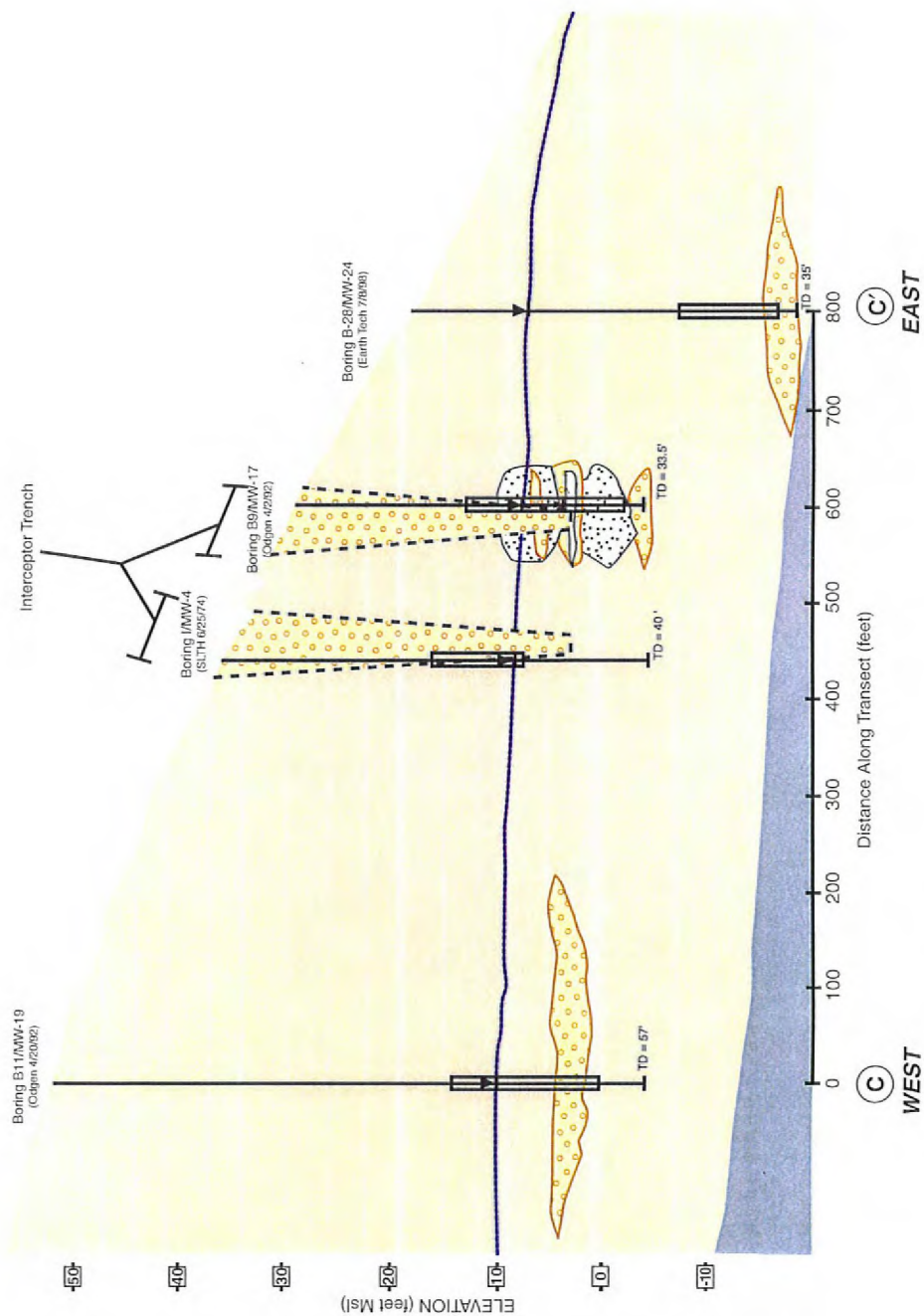


Figure 3-8
Geologic Cross Section C-C'
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



The unconfined, near-surface caprock water-bearing zone occurs within the caprock sediments and is separated from the basal groundwater by the low-permeability strata that confine the deep aquifer. The caprock water-bearing zone generally extends approximately 1 mile inland from the shoreline. The caprock groundwater is usually interconnected with the ocean, and is commonly brackish to salty due to seawater intrusion. Hydraulic conductivity of the caprock water-bearing zone is significantly less than the hydraulic conductivity of the confined basal aquifer. Phase I RI field test results (constant discharge and slug testing) suggest the average horizontal hydraulic conductivity of the caprock water-bearing zone in the onsite area is on the order of 1×10^{-3} cm/sec or less. The slope of the caprock water table (approximately 6 m/km) is significantly steeper than the potentiometric surface of the confined basal aquifer in the EJFDF area (approximately 0.3 m/km [Mink 1980]).

3.8.2 Investigation Area Hydrogeology

The shallow caprock water-bearing zone is apparently continuous throughout the investigation area, and occurs within lenses of sand and gravel interbedded with relatively impermeable silts and clays. The deep confined basal aquifer exists within the highly permeable, fractured Koolau basalts that underlie the sediments. The caprock groundwater is brackish to salty due to seawater intrusion. Although the basal groundwater is not as saline as the caprock groundwater, groundwater flowing from artesian wells that tap the confined basal aquifer downgradient of the EJFDF has been characterized as brackish.

The potentiometric surface of the confined basal aquifer is considerably higher than that of the unconfined caprock water-bearing zone (as shown in Figure 3-4). The potentiometric surface of the confined basal aquifer in the vicinity of the EJFDF has been measured at approximately 16 feet above msl (Ogden 1996), while the elevation of the caprock water table in the investigation area ranges from less than 2 to 13 feet above msl. The hydraulic gradient across the low-permeability confining strata between the two groundwater bodies is therefore directed upward, from the confined basal aquifer toward the caprock water-bearing zone. Any leakage through the confining strata would therefore also be directed upward.

The difference in hydraulic head between the two groundwater bodies is evidence of a relatively impermeable hydraulic barrier, and reflects a difference in elevation between the two recharge areas. The confined basal aquifer is recharged by heavy rainfall in the higher elevations of the Koolau Range northeast of Pearl Harbor, whereas the caprock water-bearing zone is recharged primarily by local sources, including rainfall, irrigation water, and springs supplied by the confined basal aquifer.

Groundwater sampling results provide direct evidence that caprock groundwater does not reach the confined basal aquifer in the investigation area. Although onsite monitoring well sampling results indicate that caprock groundwater at the EJFDF has been impacted by the MOGAS release, contaminants associated with the release have not been detected in groundwater samples collected from the artesian irrigation wells that tap the confined basal aquifer.

3.8.2.1 CAPROCK WATER-BEARING ZONE

The water table contour maps presented in Figure 3-9 and Figure 3-10 depict the caprock water table, as determined from depth-to-water measurements taken on 10 August 1998 and 28 April 1999. In addition to the August 1998 and April 1999 measurements, water level data were collected on 19 January and 23 March 1999 (see Appendix H). Although increased rainfall during the winter months normally causes an increase in the elevation of the water table, the water level data indicate

that very little variation in water levels occurred between August 1998 and April 1999. This is most likely the result of the unusually low rainfall recorded over the winter of 1998–1999.

The caprock water table is approximately 80 feet bgs near the northern boundary of the EJFDF, and occurs closer to the surface as the topography slopes down toward the shore of Middle Loch. Caprock water table elevations measured during the Phase II RI range from approximately 13 feet above msl in the northern portion of the EJFDF to about 2 feet above msl near the Middle Loch shoreline. The hydraulic gradient is about 2 m/km at the north end of the EJFDF and increases in the downgradient direction, reaching about 13 m/km in the watercress farm area.

Results of the Phase II RI and previous investigations indicate that caprock groundwater downgradient of the site discharges to the harbor, but does not reach the ground surface inland of the shoreline. No evidence of groundwater seeps or springs was identified during the Phase II RI surface water hydrology survey, or during surveys conducted during the Phase I RI. Hydrogeological evidence from the Phase II RI borings and wells indicates that the caprock groundwater does not discharge into the watercress fields, and that the discharge area is at or beyond the Middle Loch shoreline.

Onsite Conditions: Caprock groundwater beneath the EJFDF site occurs within layers of silty sand and gravel interbedded with relatively impermeable silts and clays. Phase I RI field test results (constant discharge, slug, and permeameter testing) suggest that the average horizontal hydraulic conductivity of the caprock water-bearing zone in the onsite area is less than 2×10^{-4} cm/sec. Hydraulic conductivity values measured by laboratory permeameter testing of samples collected from onsite borings during the Phase I RI averaged only 6.33×10^{-7} cm/sec (Ogden 1996). It should be noted that hydraulic conductivity values obtained by laboratory permeameter testing are often considerably lower than values obtained by field testing. The discrepancies are generally due to localized zones of increased transmissivity (such as the silty sand and silty gravel beds found at the EJFDF), or other discontinuities that affect in-place, subsurface hydraulic conductivity.

Offsite Conditions: Borings advanced during the Phase II RI revealed that the stratigraphy of the offsite area downgradient of the EJFDF is dominated by stiff silty clays. Caprock groundwater in the offsite area occurs within relatively thin silty sand and silty gravel layers interbedded with the silty clays, and may also occur within the underlying weathered basalts. The relatively permeable sediments that occur within the caprock water-bearing zone on site (the silty sand, silty gravel, and sandy gravel units) tend to pinch out downgradient of the EJFDF. Offsite stratigraphy and geotechnical laboratory test results suggest that average hydraulic conductivities downgradient of the EJFDF are significantly lower than in the onsite area. Saturated hydraulic conductivity of three silty clay samples collected from offsite borings (measured by laboratory permeameter testing) ranged between 1.5×10^{-8} cm/sec and 8.8×10^{-7} cm/sec (typical of unweathered marine clays [Freeze and Cherry 1979]). The saturated hydraulic conductivity of a silty sand layer encountered in one of the offsite borings was measured at 4.9×10^{-5} cm/sec (typical of silty sand [Freeze and Cherry 1979]).

LEGEND

—10—

Caprock Water Table Elevation Contour (feet above msl)

(10.51)

Caprock Water Table Elevation (feet above msl)

●

Monitoring Well Location (MW-#)

○

Monitoring Well Location (MW-#)

—

Fence

—

Paved Road

—

Dirt Road

—

Edge of Mangrove Swamp

—

Watercess Patch

—

Pond or Stream

NOTES

NM Not Measured

SOURCE

Water Level Measurements Collected on 10 August 1998.

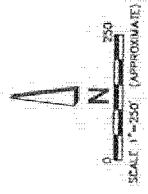
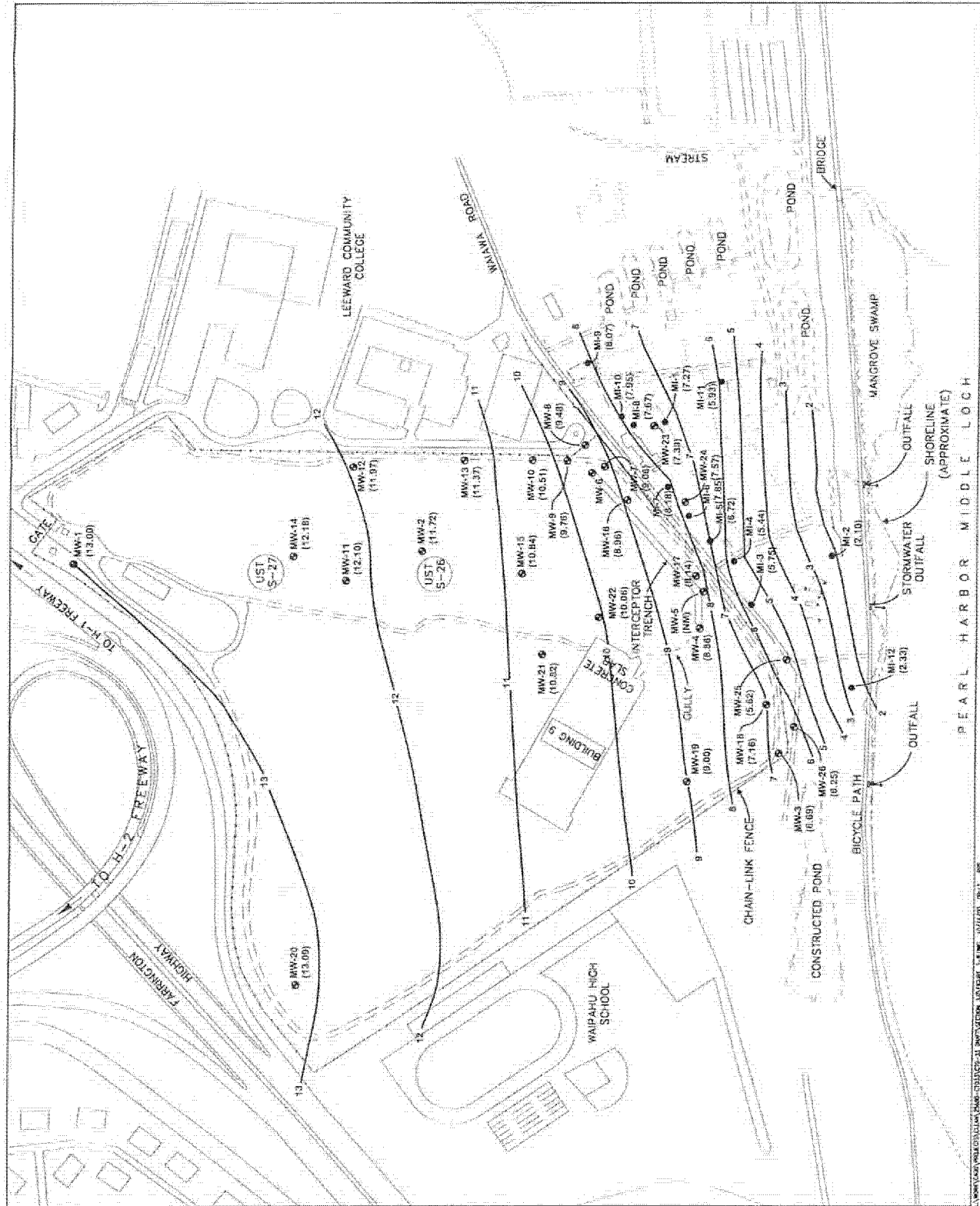


Figure 3-9
Caprock Water Table Elevations,
10 August 1998
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



LEGEND

10

Caprock Water Table Elevation Contour (feet above msl)

(10.39)

Caprock Water Table Elevation (feet above msl)

*

Microwell Location (MW-9)

○

Monitoring Well Location (MW-24)

—

Fence

—

Paved Road

—

Dirt Road

—

Edge of Mangrove Swamp

—

Watercress Patch

—

Pond or Stream

NOTES

NM Not Measured

SOURCE

Water Level Measurements Collected on 28 April 1999

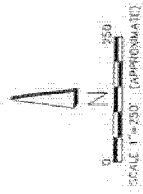
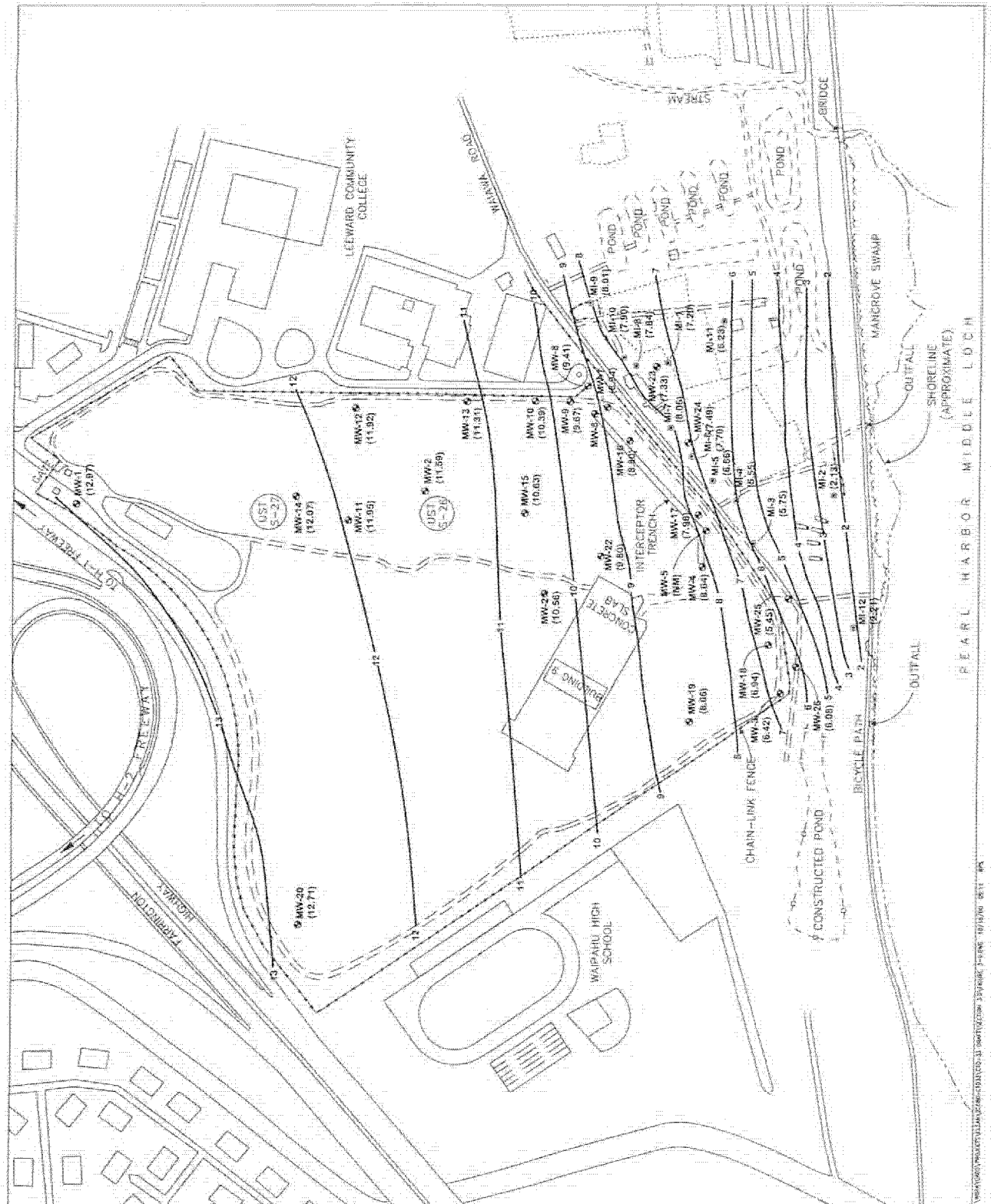


Figure 3-10
Caprock Water Table Elevations,
28 April 1999
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



Although caprock groundwater beneath the EJFDF site is unconfined, the caprock water-bearing zone in the offsite area appears to exist under confined or semi-confined conditions. Strata overlying the caprock water-bearing zone in the offsite area are predominantly low-permeability silty clays. The low-permeability layers appear to form confining units above the water-bearing zone. (The hydraulic conductivity of one sample of the silty clay, as measured by laboratory permeameter testing, was only 1.5×10^{-8} cm/sec.) As shown in Table 3-4, water levels in the offsite wells stabilized as much as 23 feet higher than the levels at which saturated sediments were first encountered when the borings were advanced.

Table 3-4: Water Levels Noted in Borings versus Static Water Levels in Corresponding Wells

Boring Number	Well Number	Initial Groundwater Encountered in Boring (feet above msl) ^a	Static Water Level (feet above msl) ^b	Increase in Water Level (feet)
B-02	MI-1	-12.63	7.00	19.63
B-03	MI-2	-4.34	2.10	6.44
B-06	MI-3	0.43	5.75	5.32
B-07	MI-4	-2.74	5.44	8.18
B-08	MI-5	-1.73	6.72	8.45
B-09	MI-6	Uncertain ^c	7.85	—
B-10	MI-7	Uncertain ^c	8.18	—
B-16	MI-8	-10.85	7.67	18.52
B-17	MI-9	-1.27	8.07	9.34
B-20	MI-10	-15.33	7.95	23.28
B-23	MI-11	Uncertain ^c	5.93	—
B-25	MI-12	Uncertain ^c	2.33	—
B-27	MW-23	-11.56	7.39	18.95
B-28	MW-24	-9.58	7.57	17.15
B-29	MW-25	2.84	5.62	2.78
B-30	MW-26	Uncertain ^c	6.25	—

— = not available

^a Level at which saturated sediments were first encountered as boring was advanced.

^b Static water level (10 August 1998)

^c Water level could not be precisely determined in boring.

The water level data and topography of the watercress farm area appear to indicate that it is possible for the potentiometric surface of the caprock water-bearing zone to reach elevations high enough to intersect the bottom of the watercress patches in some areas. However, discharge from the caprock water-bearing zone into the watercress ponds is highly unlikely. Discharge would be possible only if the potentiometric surface of the caprock water-bearing zone were to rise above the surface water level in the ponds. The groundwater level and surface water elevation data indicate that the pond water elevations are above the level of the caprock groundwater potentiometric surface (as shown in Figure 3-4). The height of the surface water above the potentiometric surface results in a downward-directed hydraulic gradient across the low-permeability strata between the surface water and the groundwater; therefore, if discharge occurred, it would be directed downward, from the watercress ponds into the caprock groundwater, rather than upward into the ponds.

It is important to note, however, that neither upward nor downward discharge is likely because the low-permeability silty clays overlying the caprock water-bearing zone in the watercress farm area form confining units above the water-bearing zone. Although it was suspected that recharge from surface water could cause caprock groundwater "mounding" (a local increase in water table elevation) in the watercress field area, the Phase II RI water table measurements did not reveal any mounding effects. This suggests that offsite-area surface water does not significantly recharge the caprock water-bearing zone. The low-permeability clay and silty clay units that overlie the caprock water-bearing zone in the offsite area appear to form a hydraulic barrier between the caprock groundwater and surface water. The caprock groundwater body itself was not encountered in the watercress pond-area borings until the borings reached depths below sea level: e.g., in the MI-2 and MI-4 borings, groundwater was first encountered at depths of 4.34 and 2.74 feet below sea level, respectively (see Table 3-4). Therefore, the hydrogeologic evidence indicates that the caprock water-bearing zone actually occurs at depths well below the bottoms of the watercress ponds. In summary, the hydrogeologic evidence indicates that discharge from the caprock-water bearing zone into the watercress ponds is highly unlikely.

Potential for Exposure. As discussed below, hydrogeologic evidence and analytical data from the Phase II RI and previous investigations indicate that contaminants in the caprock groundwater are not likely to reach the surface in the investigation area, or impact the confined basal aquifer.

Findings of the Phase II RI hydrogeologic investigation indicate that offsite caprock groundwater does not reach the ground surface in the agricultural/wetlands area downgradient of the site. In addition, Phase I and Phase II RI findings show that, in the onsite area, caprock groundwater remains at least 20 feet bgs. No caprock groundwater springs or seeps have been observed at the EJFDF or off site.

It is highly unlikely that either the unnamed stream that flows along the eastern margin of the offsite investigation area or the Waiawa Unit of the Pearl Harbor National Wildlife Refuge is impacted by the EJFDF MOGAS release. As shown in Section 4, the groundwater contaminant plume associated with the MOGAS release extends toward the south and southwest, and is essentially confined within the EJFDF site boundary. The plume geometry is strong evidence that the hydrogeological characteristics of the investigation area cause groundwater from the onsite area to flow toward the south and southwest—not southeast toward the unnamed stream and the Waiawa Unit. Furthermore, as noted in Section 3.1.3, water for the Waiawa Unit is not drawn from the unnamed stream. The water source for the refuge is the freshwater marsh east of Nakatani Farm. This freshwater marsh is located more than 1,500 feet east of the southeast corner of the site. The marsh is thus crossgradient from the EJFDF, not downgradient (the hydraulic gradient is directed toward the south (see Figure 3-9 and Figure 3-10). Therefore, it is not possible for groundwater from the site to impact the water source for the wildlife refuge.

Phase I and Phase II RI groundwater sampling results indicate that concentrations of contaminants related to the EJFDF MOGAS spill decrease to very low levels well before the contaminant plume reaches the downgradient site boundary, and that the areal extent of the contaminant plume is decreasing with time. The decreases in contaminant concentrations and plume area are attributed to natural attenuation. As discussed in Section 5, the biodegradation capacity of EJFDF caprock groundwater is more than sufficient to completely degrade even the highest BTEX concentrations that have been detected. The Phase II RI groundwater sampling results indicate that even if discharge did occur in the watercress farm area, contaminant concentrations in the offsite caprock groundwater are well below levels that would pose unacceptable risks to human health or the environment.

Phase I and Phase II RI findings indicate that EJFDF caprock groundwater has not impacted the deep confined basal aquifer (the source of the artesian well water used to irrigate the watercress fields). The observed hydrogeologic characteristics of the investigation area (i.e., the low-permeability confining layers that separate the two groundwater bodies and the upward-directed hydraulic gradient) indicate that the EJFDF caprock groundwater is not connected to the confined basal aquifer.

As discussed in detail in Section 8.1.4, the caprock groundwater cannot be considered a current or potential drinking water source. Human exposure is therefore highly unlikely. In the offsite area, neither the caprock water-bearing zone nor the confined basal aquifer are classified as drinking water sources according to the DOH report *Aquifer Identification and Classification for Oahu* (Mink and Lau 1990).

4. NATURE AND EXTENT OF CONTAMINATION

Results of the Phase II RI field sampling and analysis program are evaluated in terms of nature (the type and concentration of contaminants) and extent (the spatial distribution of contaminants). A listing of all samples and analyses is presented in Appendix I. As discussed in Section 2, the primary objectives of the Phase II RI are to evaluate the potential impact of MOGAS constituents from the 1971 release on the human and ecological receptors in the offsite area downgradient of the EJFDF. This evaluation therefore focuses on MOGAS-related contaminants detected in the offsite area and MOGAS-related contaminants that may migrate from the EJFDF to the offsite area. The evaluation also considers other detected contaminants that are unrelated to the 1971 MOGAS release.

Contamination associated with the MOGAS release has remained almost completely within the EJFDF site boundary. MOGAS constituents detected onsite consist of light-end hydrocarbons commonly found in gasoline products, such as BTEX compounds, 1,2-DCA, and phenolic and naphthalene compounds in the C2–C12 hydrocarbon range. Lead levels in onsite subsurface soils and caprock groundwater are very low. In the offsite area, contaminants potentially associated with the MOGAS release were detected in only a few of the subsurface soil and caprock groundwater samples collected along Waiawa Road just south of the site boundary; the detected concentrations were very low (well below risk-based screening criteria).

Contaminants that warrant further evaluation are identified by comparing the concentrations detected in soil, sediment, surface water, and groundwater to risk-based screening criteria. Chemical-specific ARARs or TBC criteria identified for the EJFDF are used as screening criteria. The rationale used to identify ARARs and TBCs for the EJFDF is presented in Section 8. Contaminants detected at concentrations above the screening criteria and contaminants without screening criteria are further evaluated in the human health and ecological risk assessments presented in Sections 6 and 7.

The analytical data tables in this section list only analytes that were detected at concentrations above the method reporting limit (MRL) in one or more samples. Analytes not detected at concentrations above MRLs are not listed. Complete analytical data (including MRLs for all analytes) are presented in Appendix I.

4.1 SURFACE SOIL, SEDIMENT, AND SURFACE WATER

Surface soil, sediment, and surface water samples were collected from the offsite area downgradient of the EJFDF in June 1998. These samples were analyzed for the following constituents:

- TPH-gasoline and TPH-diesel by EPA Solid Waste (SW) 846 Method 8015B
- VOCs and SVOCs by CLP OLM 03.1
- Selected PAHs by EPA SW 846 Method 8270C selective ion monitoring (SIM)
- Lead by CLP ILM 04.0

4.1.1 Surface Soil

Five offsite surface soil samples were collected in the area north of the Oshita watercress patch where petroleum contamination was reportedly observed in August 1995 during excavation of a sewer line trench, as described in Section 2 (Okada 1995). Table 4-1 lists the concentrations detected in surface soil samples, and Figure 4-1 shows concentrations detected at each sample location.

Table 4-1: Offsite Surface Soil Detections of Organic Compounds and Lead

Analyte	EPA Region IX Residential Soil PRG	Offsite Sampling Location				
		S-01	S-02	S-03	S-04	S-05
SVOCs (µg/kg) by CLP OLM 03.1 and PAHs by EPA 8270C SIM						
Anthracene	14,000,000	5U	5U	5U	3.29J	5U
Benzo(a)anthracene	560	11.13J	12J	15.82J	16.97J	21J
Benzo(a)pyrene	56	10.38J	14J	16.9J	12.22J	13J
Benzo(b)fluoranthene	560	23.22J	26.14J	34.15J	26.65J	24J
Benzo(g,h,i)perylene	ns	10.71J	16J	33.36J	13.66J	9.64J
Benzo(k)fluoranthene	5,600	9J	19J	11J	7J	20J
BEHP	320,000	36.47J	39.77J	330U	330U	59.86J
Chrysene	56,000	14.79J	21J	23.23J	13.75J	27J
Dibenzo(a,h)anthracene	56	330U	9.92J	16.05J	330U	330U
Fluoranthene ^a	2,000,000	18.85J	29J	24.03J	31.71J	28J
Indeno(1,2,3-cd)pyrene	560	9J	18J	13J	7J	11J
Phenanthrene	ns	5U	10J	8J	13.64J	5U
Pyrene	1,500,000	17.8J	23J	26.96J	31.94J	27J
Lead (mg/kg) by CLP ILM 04.0						
Lead	400	25.29J	19.97J	39.01J	44.32J	22.65J

Notes:

All sampling depths are 0–0.5 feet bgs.

Data qualifiers are defined in Section 4.5.

µg/kg = microgram per kilogram

ns = no standard; no surface soil criteria established.

Bold italic number = detected concentration above the MRL but below the screening criteria.

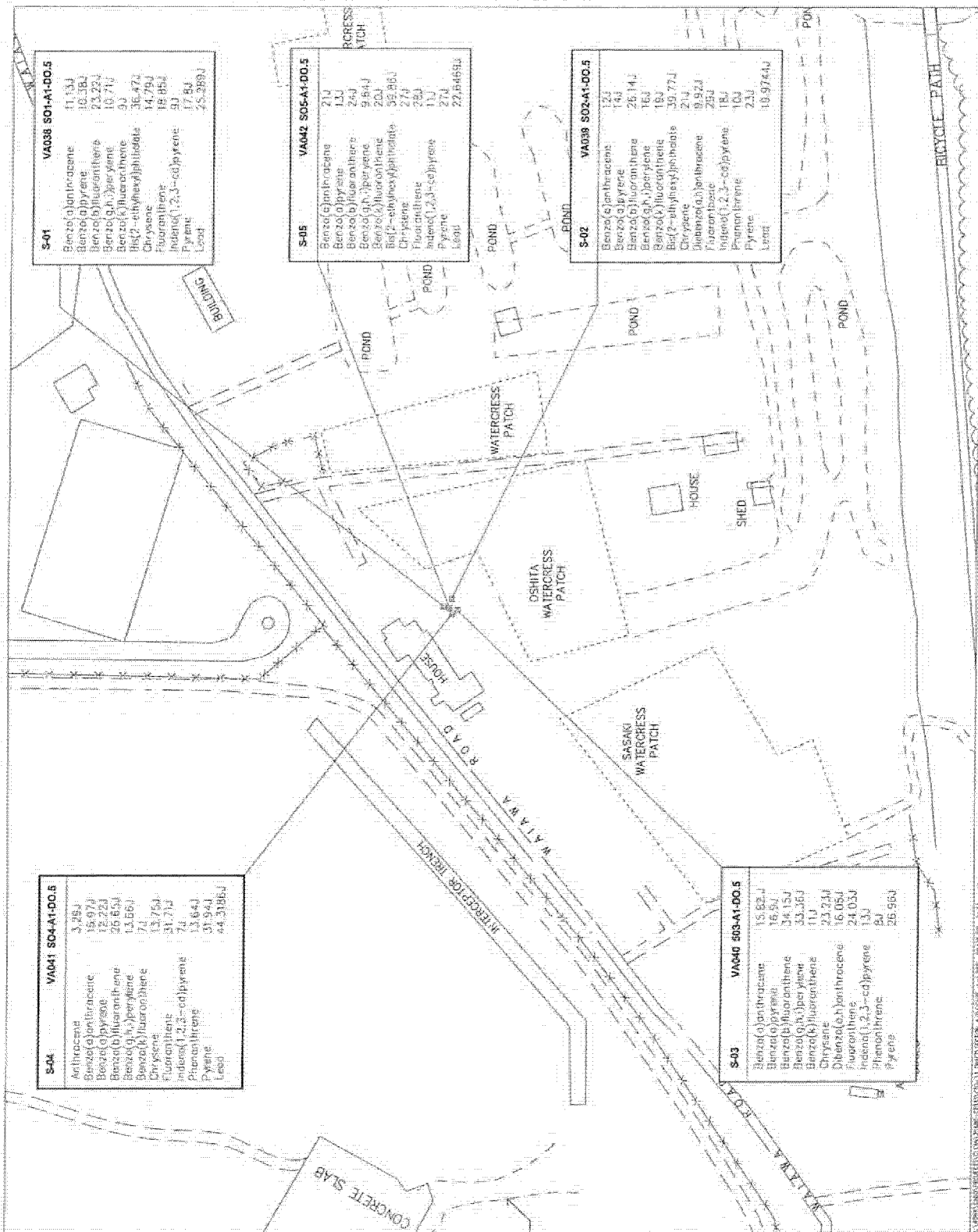
EPA SW 846 Method 8270C SIM analysis used for PAHs.

^a The DOH Tier 1 action level for this compound is lower than the corresponding PRG, and is therefore used in place of the less-conservative PRG value.

Surface Soil Screening Criteria. For TPH, State of Hawaii Department of Health (DOH) (1995b,c, 1996a,b) Tier 1 action levels for soil were used as screening criteria. The DOH Tier 1 action levels for soil are divided into two categories: drinking water source threatened and not threatened. (The action levels for TPH are the same for both categories.) The DOH Tier 1 TPH soil action levels cover three carbon ranges:

- TPH-gasoline (carbon range C6–C12). Phase II RI soil samples were analyzed for TPH-gasoline in the C8–C11 range.
- TPH-middle distillates (carbon range C12–C24). Phase II RI soil samples were analyzed for TPH-kerosene in the C11–C14 range, and TPH-diesel in the C14–C20 range. Detected TPH-kerosene and TPH-diesel concentrations were combined for comparison to the middle distillates criteria.
- TPH-residual fuels (carbon range >C24). Phase II RI soil samples were not analyzed for this TPH range.

For VOCs and SVOCs (including PAHs) and lead, EPA Region IX PRGs for soil in residential areas are used as screening criteria.



For three PAH compounds (naphthalene, acenaphthene, and fluoranthene), the DOH Tier 1 action levels are lower than the corresponding PRGs and are therefore used in place of the less-conservative PRG criteria. Screening criteria for surface soil samples are described in more detail in Section 8.1.1.

TPH and VOC Results. TPH and VOCs were not detected at concentrations above the MRL in any of the surface soil samples. (The MRL for the VOC surface soil analyses ranged from 11.43 to 11.66 micrograms per kilogram [$\mu\text{g/kg}$]; the TPH MRL ranged from 1.1 to 12 milligrams per kilogram [mg/kg].)

SVOC Results. All samples contained SVOCs at concentrations above the MRLs. The detected SVOCs include several high-molecular-weight (HMW) PAHs and BEHP, at concentrations ranging from 10 to 60 $\mu\text{g/kg}$. No SVOCs were detected at concentrations exceeding their screening criteria.

Lead Results. Lead was detected at concentrations above the MRL in all five surface soil samples. The detected concentrations range from 22 to 45 mg/kg , all below the EPA Region IX residential PRG of 400 mg/kg .

4.1.2 Sediment and Surface Water

Collocated sediment and surface water samples were collected at ten locations (Figure 4-2). Samples were collected from the watercress patches, from streams that drain into Middle Loch, and along the harbor shoreline. Table 4-2 and Table 4-3 list the analytes detected in the sediment and surface water samples, respectively.

Sediment Screening Criteria. Two sets of screening values are used as screening criteria for VOCs, SVOCs, and lead in sediment:

- Effects range-low (ER-L) for marine sediment (Long et al. 1995). ER-Ls are used to screen samples D-01 and D-02, which were collected along the shoreline.
- Threshold effect level (TEL) for freshwater sediment (Smith et al. 1996). TELs are used to screen samples D-03 through D-10, which were collected in the (freshwater) agricultural area.

Screening criteria for sediments are described in more detail in Section 8.1.3.

Surface Water Screening Criteria. Hawaii DOH water quality standards (WQSS) (Hawaii Administrative Rules [HAR] Title 11-54), National Recommended Water Quality Criteria (NRWQC) (EPA 1999b), and Great Lakes Tier II (Suter and Tsao 1996) values were used as screening criteria for VOCs, SVOCs, and lead in surface water:

- Chronic marine criteria were used to screen samples W-01, W-02, W-04, W-06, and W-09.
- Chronic freshwater criteria were used to screen samples W-03, W-05, W-07, W-08, and W-10.

No screening values were identified for TPH in marine or fresh surface water because no TPH criteria were identified as ARARs or TBCs for surface water. Screening criteria for surface water are described in more detail in Sections 7 and 8.

TPH Results

TPH concentrations are below the MRL in all sediment and surface water samples.

VOC Results

Sediment. Eight of the eleven sediment samples contained at least one of three VOCs (acetone, 2-butanone, carbon disulfide) at concentrations above the MRL. The detected VOCs are common laboratory reagents. Detected acetone and 2-butanone concentrations range from 16 to 75 µg/kg and from 6 to 26 µg/kg, respectively, as illustrated in Figure 4-2. Carbon disulfide was detected in one sample (D-10 duplicate) at 8 µg/kg. No TEL or ER-L sediment screening values are available for comparison to sediment VOC results.

Surface Water. VOC concentrations in all surface water samples are below the MRL (10 µg/L).

SVOC Results

Sediment. SVOC concentrations above the MRLs were detected in all sediment samples. Sample D-05, collected from the Oshita watercress patch, contained four PAHs (benzo(a)anthracene, benzo(a)pyrene, chrysene, and pyrene) at concentrations above TEL sediment screening values. Samples D-04, D-05 and D-09 also contained elevated concentrations of several other PAHs with no TEL standards. Samples D-04 and D-05 were collected from the stream south of the Oshita watercress patch. The detected PAHs (in the C16–C22 range) are heavier than compounds found in MOGAS; therefore, they are not likely to be related to the 1971 MOGAS release (see Appendix J for MOGAS product specifications). An elevated BEHP concentration (estimated 1,798 µg/kg) was detected in marine sediment sample D-01, which was collected near a storm sewer outfall to the harbor (see Figure 4-2). BEHP was also detected in the watercress patch freshwater sediment samples; however, concentrations were much lower (similar to the levels observed in surface soil samples). BEHP is a common contaminant in urban environments and stormwater runoff, and is also a common laboratory contaminant. Because caprock groundwater does not discharge to the watercress farm area and because BEHP is not a typical gasoline constituent, the BEHP detected in sediments is not likely to be related to the 1971 MOGAS release.

Surface Water. Six surface water samples contained SVOCs at concentrations exceeding the MRL. These surface water analytes are included in the human health and ecological risk assessments (Sections 6 and 7).

One surface water sample (W-06) collected from the Sasaki watercress patch contained several HMW PAHs, including fluoranthene, pyrene, chrysene, benzo(a,h)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, dibenzo(a,h)anthracene, indeno(1,2,3)pyrene, and phenanthrene. Water samples W-03 and W-10, collected from the Oshita and Sasaki watercress patches, respectively, contained only two or three HMW PAHs. PAH concentrations detected in water samples W-03, W-06, and W-10 are only slightly above the MRLs. These HMW PAHs were also detected in sediment and surface soil samples collected in the watercress farm area. Due to their high molecular weights (C16–C22) and boiling points, these PAHs are not likely to be associated with the 1971 MOGAS release. Benzo(a)pyrene has a boiling point of 925°F, whereas the maximum boiling point reported for the Ewa Junction MOGAS product is 430°F.) An elevated BEHP concentration was detected in surface water sample W-01, collected next to the storm sewer outfall to the harbor (see Figure 4-2). The BEHP detections are not likely to be related to the MOGAS release. This analyte is a common contaminant in urban stormwater discharge, and is also a common laboratory contaminant.

U.S. NAVY COLLEGE

PEARL HARBOR

Map Labels: D-03, D-07, W-06, D-08, W-01, D-01, D-02, W-02, D-04, W-04, D-05, W-05, D-06, W-06, D-07, W-07, D-08, W-08, D-09, W-09, D-10, W-10, D-11, W-11, D-12, W-12, D-13, W-13, D-14, W-14, D-15, W-15, D-16, W-16, D-17, W-17, D-18, W-18, D-19, W-19, D-20, W-20, D-21, W-21, D-22, W-22, D-23, W-23, D-24, W-24, D-25, W-25, D-26, W-26, D-27, W-27, D-28, W-28, D-29, W-29, D-30, W-30, D-31, W-31, D-32, W-32, D-33, W-33, D-34, W-34, D-35, W-35, D-36, W-36, D-37, W-37, D-38, W-38, D-39, W-39, D-40, W-40, D-41, W-41, D-42, W-42, D-43, W-43, D-44, W-44, D-45, W-45, D-46, W-46, D-47, W-47, D-48, W-48, D-49, W-49, D-50, W-50, D-51, W-51, D-52, W-52, D-53, W-53, D-54, W-54, D-55, W-55, D-56, W-56, D-57, W-57, D-58, W-58, D-59, W-59, D-60, W-60, D-61, W-61, D-62, W-62, D-63, W-63, D-64, W-64, D-65, W-65, D-66, W-66, D-67, W-67, D-68, W-68, D-69, W-69, D-70, W-70, D-71, W-71, D-72, W-72, D-73, W-73, D-74, W-74, D-75, W-75, D-76, W-76, D-77, W-77, D-78, W-78, D-79, W-79, D-80, W-80, D-81, W-81, D-82, W-82, D-83, W-83, D-84, W-84, D-85, W-85, D-86, W-86, D-87, W-87, D-88, W-88, D-89, W-89, D-90, W-90, D-91, W-91, D-92, W-92, D-93, W-93, D-94, W-94, D-95, W-95, D-96, W-96, D-97, W-97, D-98, W-98, D-99, W-99, D-100, W-100, D-101, W-101, D-102, W-102, D-103, W-103, D-104, W-104, D-105, W-105, D-106, W-106, D-107, W-107, D-108, W-108, D-109, W-109, D-110, W-110, D-111, W-111, D-112, W-112, D-113, W-113, D-114, W-114, D-115, W-115, D-116, W-116, D-117, W-117, D-118, W-118, D-119, W-119, D-120, W-120, D-121, W-121, D-122, W-122, D-123, W-123, D-124, W-124, D-125, W-125, D-126, W-126, D-127, W-127, D-128, W-128, D-129, W-129, D-130, W-130, D-131, W-131, D-132, W-132, D-133, W-133, D-134, W-134, D-135, W-135, D-136, W-136, D-137, W-137, D-138, W-138, D-139, W-139, D-140, W-140, D-141, W-141, D-142, W-142, D-143, W-143, D-144, W-144, D-145, W-145, D-146, W-146, D-147, W-147, D-148, W-148, D-149, W-149, D-150, W-150, D-151, W-151, D-152, W-152, D-153, W-153, D-154, W-154, D-155, W-155, D-156, W-156, D-157, W-157, D-158, W-158, D-159, W-159, D-160, W-160, D-161, W-161, D-162, W-162, D-163, W-163, D-164, W-164, D-165, W-165, D-166, W-166, D-167, W-167, D-168, W-168, D-169, W-169, D-170, W-170, D-171, W-171, D-172, W-172, D-173, W-173, D-174, W-174, D-175, W-175, D-176, W-176, D-177, W-177, D-178, W-178, D-179, W-179, D-180, W-180, D-181, W-181, D-182, W-182, D-183, W-183, D-184, W-184, D-185, W-185, D-186, W-186, D-187, W-187, D-188, W-188, D-189, W-189, D-190, W-190, D-191, W-191, D-192, W-192, D-193, W-193, D-194, W-194, D-195, W-195, D-196, W-196, D-197, W-197, D-198, W-198, D-199, W-199, D-200, W-200, D-201, W-201, D-202, W-202, D-203, W-203, D-204, W-204, D-205, W-205, D-206, W-206, D-207, W-207, D-208, W-208, D-209, W-209, D-210, W-210, D-211, W-211, D-212, W-212, D-213, W-213, D-214, W-214, D-215, W-215, D-216, W-216, D-217, W-217, D-218, W-218, D-219, W-219, D-220, W-220, D-221, W-221, D-222, W-222, D-223, W-223, D-224, W-224, D-225, W-225, D-226, W-226, D-227, W-227, D-228, W-228, D-229, W-229, D-230, W-230, D-231, W-231, D-232, W-232, D-233, W-233, D-234, W-234, D-235, W-235, D-236, W-236, D-237, W-237, D-238, W-238, D-239, W-239, D-240, W-240, D-241, W-241, D-242, W-242, D-243, W-243, D-244, W-244, D-245, W-245, D-246, W-246, D-247, W-247, D-248, W-248, D-249, W-249, D-250, W-250, D-251, W-251, D-252, W-252, D-253, W-253, D-254, W-254, D-255, W-255, D-256, W-256, D-257, W-257, D-258, W-258, D-259, W-259, D-260, W-260, D-261, W-261, D-262, W-262, D-263, W-263, D-264, W-264, D-265, W-265, D-266, W-266, D-267, W-267, D-268, W-268, D-269, W-269, D-270, W-270, D-271, W-271, D-272, W-272, D-273, W-273, D-274, W-274, D-275, W-275, D-276, W-276, D-277, W-277, D-278, W-278, D-279, W-279, D-280, W-280, D-281, W-281, D-282, W-282, D-283, W-283, D-284, W-284, D-285, W-285, D-286, W-286, D-287, W-287, D-288, W-288, D-289, W-289, D-290, W-290, D-291, W-291, D-292, W-292, D-293, W-293, D-294, W-294, D-295, W-295, D-296, W-296, D-297, W-297, D-298, W-298, D-299, W-299, D-300, W-300, D-301, W-301, D-302, W-302, D-303, W-303, D-304, W-304, D-305, W-305, D-306, W-306, D-307, W-307, D-308, W-308, D-309, W-309, D-310, W-310, D-311, W-311, D-312, W-312, D-313, W-313, D-314, W-314, D-315, W-315, D-316, W-316, D-317, W-317, D-318, W-318, D-319, W-319, D-320, W-320, D-321, W-321, D-322, W-322, D-323, W-323, D-324, W-324, D-325, W-325, D-326, W-326, D-327, W-327, D-328, W-328, D-329, W-329, D-330, W-330, D-331, W-331, D-332, W-332, D-333, W-333, D-334, W-334, D-335, W-335, D-336, W-336, D-337, W-337, D-338, W-338, D-339, W-339, D-340, W-340, D-341, W-341, D

Figure 4-2
Organic Compounds and Lead Concentrations
in Sediment and Surface Water

**Ewa Junction Fuel Drumming Facility
Phase II RI
in Sediment and Surface Water
Pearl Harbor, Oahu, Hawaii**

Table 4-2: Sediment Detections of Organic Compounds and Lead, EJFDF Phase II RI

Analyte	Marine Sediment			Freshwater Sediment										
	Screening Criteria (ER-Ls) ^a	Offsite Sampling Location		Screening Criteria (TELs) ^b	Offsite Sampling Location									
		D-01	D-02		D-03	D-04	D-05	D-06	D-07	D-08	D-09	D-10	D-10 Duplicate	
Volatiles (µg/kg) by CLP OLM 03.1														
Acetone	ns	16.59J	16.81U	ns	23.26UJ	28.82U	21.58J	74.84J	23.65J	15.43U	57.81J	60.72J	67.66J	
2-Butanone	ns	6.89J	16.81U	ns	18.78J	28.82U	15.29UJ	26.89J	16.34U	15.43U	24.46J	25.62J	37.45UJ	
Carbon disulfide	ns	13.53U	16.81U	ns	23.26UJ	28.82U	15.29UJ	37.74UJ	16.34U	15.43U	21.55UJ	28.65UJ	8.36J	
SVOCs (µg/kg) by CLP OLM 03.1 and PAHs by EPA 8270C SIM														
4-Bromophenyl-phenylether	ns	446.5U	554.6U	ns	767.4UJ	951UJ	504.6UJ	330UJ	330U	330U	197.1J	945.6UJ	1,236UJ	
Anthracene	85.3	5U	5U	ns	5UJ	5UJ	12J	5UJ	5U	5U	5U	5U	5UJ	
Benzo(a)anthracene	261	14J	5U	31.7	22J	6J	42J	11J	5U	5U	23.69J	13J	5UJ	
Benzo(a)pyrene	430	9J	5U	31.9	24J	12J	50J	5UJ	5U	5U	19.56J	5U	5UJ	
Benzo(b)fluoranthene	ns	13J	5U	ns	28J	47.94J	82J	15.3J	5U	5U	41.76J	14J	12J	
Benzo(g,h,i)perylene	ns	21J	5U	ns	22J	115.7J	70J	11J	5U	5U	5U	11J	7J	
Benzo(k)fluoranthene	ns	7J	5U	ns	27.18J	11J	66J	12J	5U	5U	5U	13J	9J	
BEHP	ns	1,798J	554.6U	ns	42.47J	73.63J	25.57J	66.8J	26.61J	30.7J	34.06J	945.6UJ	1,236UJ	
Chrysene	384	30J	5U	57	41J	27.33J	70J	16J	5U	5U	22.31J	14J	8J	
Dibenzo(a,h)anthracene	63.4	446.5U	554.6U	ns	767.4UJ	951UJ	20.97J	330UJ	330U	330U	711.2U	945.6UJ	1,236UJ	
Diethylphthalate	ns	446.5U	554.6U	ns	767.4UJ	41.3J	504.6UJ	330UJ	330U	330U	711.2U	945.6UJ	1,236UJ	
Fluoranthene	600	20J	5J	111	58J	24J	84J	22J	6J	5U	5U	25J	19J	
Hexachlorobutadiene	ns	446.5U	554.6U	ns	767.4UJ	951UJ	504.6UJ	330UJ	330U	330U	711.2U	945.6UJ	1,236UJ	
Indeno(1,2,3-cd)pyrene	ns	9J	5U	ns	27J	28.93J	79J	16J	5U	5U	5U	13J	8J	
Phenanthrene	240	26J	5U	41.9	21J	14J	18J	8J	5U	5U	5U	8J	7J	
Phenol	ns	44.65UJ	554.6U	ns	61.2J	951UJ	504.6UJ	330UJ	330U	330U	38.06J	945.6UJ	1,236UJ	
Pyrene	665	67J	5U	53	47J	40.86J	66J	20J	5U	5U	5U	20J	18J	
Lead (mg/kg) by CLP ILM 04.0														
Lead	46.7	22.98J	9.64J	35	42.39J	26.03J	8.67J	56.14J	4.52J	5.24J	7.63J	25.25J	12.32J	

Notes: Data qualifiers are defined in Section 4.5.

All sampling depths = 0-0.5 feet.

Samples D-01 and D-02 were collected along the shoreline of the harbor and screened against marine sediment criteria.

ns = no screening criteria available.

Bold italic number = detected concentration above the MRL but below the screening criteria.**Boxed** number = detected concentration above the screening criteria.^a Effects range-low (Long et al. 1995)^b Threshold effect level (Smith et al. 1996)

Table 4-3: Surface Water Detections of Organic Compounds and Lead, EJFDF Phase II RI

COPEC	Marine						Freshwater									
	Hawaii Chronic WQS	Great Lakes Tier II	Offsite Sampling Location				Hawaii Chronic WQS	NRWQC	Great Lakes Tier II	Offsite Sampling Location						
			W-01	W-02	W-04	W-06				W-09	W-03	W-05	W-07	W-08	W-10	
SVOCs (µg/L) by CLP OLM 03.1																
Benzo(a)anthracene	NS	NS	0.027	0.02U	0.02U	0.02U	0.02U	11J	NS	NS	0.027	0.02U	0.02U	NW	NW	0.02U
Benzo(a)pyrene	NS	NS	0.014	0.02U	0.02U	0.02U	0.02U	11J	NS	NS	0.014	0.02U	0.02U	NW	NW	0.02U
Benzo(b)fluoranthene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	NS	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(g,h,i)perylene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	11J	NS	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(k)fluoranthene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	NS	NS	NS	0.02U	0.02U	NW	NW	0.02U
BEHP	NS	360	3.0	8.7J	0.83J	10U	10U	10U	NS	360	32	0.405J	10U	NW	NW	10U
Butylbenzylphthalate	NS	3.4 C	19.0	10U	10U	2.4J	10U	10U	NS	3.0 C	19	0.501J	10U	NW	NW	10U
Chrysene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	15J	NS	NS	NS	0.02U	0.02U	NW	NW	0.02U
Di-n-octylphthalate	NS	3.4 C	NS	0.643J	10U	0.865J	10U	10U	NS	3.0 C	NS	10U	10U	NW	NW	0.02U
Dibenzo(a,h)anthracene	NS	NS	NS	10U	10U	10U	0.337J	10U	NS	NS	NS	10U	10U	NW	NW	10U
Fluoranthene	NS	16	NS	0.02U	0.02U	0.02U	0.02U	33J	NS	16 sw	NS	18J	0.02U	NW	NW	16J
Indeno(1,2,3-cd)pyrene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	NS	NS	NS	0.02U	0.02U	NW	NW	0.02U
2-Nitrophenol	NS	NS	300	10U	10U	10U	10U	10U	NS	150 C	300	2.35J	10U	NW	NW	10U
Phenanthrene	NS	6.3	NS	0.02U	0.02U	0.02U	0.02U	16J	NS	4.6	NS	11J	0.02U	NW	NW	0.02U
Pyrene	NS	NS	NS	10U	0.02U	0.02U	0.02U	27J	NS	NS	NS	17J	0.02U	NW	NW	16J
Lead (µg/L) by EPA 6010A																
Lead	5.6	8.1	NS	8.38J	1U	2.18J	79.71J	ND	29	2.5	NS	22.73J	97.58J	NW	NW	22.91J

Notes: Surface water samples with VOC and SVOC concentrations below the MRLs are not included in this table.

Data qualifiers are defined in Section 4.5.

C = Screening value developed for a chemical class.

sw = If no freshwater criteria are available, saltwater criteria used as a surrogate.

NW = No water present at site at time of sampling

NS = No state or federal standard

Bold italic number = detected concentration above the MRL but below the screening criteria.**Boxed** number = detected concentration above the screening criteria. HQ exceeds 1.

Lead Results

Sediment. All 11 sediment samples contained lead at concentrations above the MRL. Lead concentrations range from approximately 4.5 to 56.1 mg/kg. Lead concentrations detected in two sediment samples (D-03 and D-06) exceed the TEL screening value (35 mg/kg): sample D-03 (42.39 mg/kg) collected in the Oshita watercress patch, and sample D-06 (56.14 mg/kg) collected at the west end of Sasaki watercress patch. Lead concentrations detected in the sediment samples are similar to lead levels in surface soil samples collected north of the Oshita watercress patch (see Figure 4-1 and Table 4-1).

Surface Water. Six of the eight surface water samples contained lead at concentrations above the MRL. Lead concentrations in two of the marine samples exceed both the WQS and NRWQC for lead in saltwater. Lead concentrations in three of the freshwater samples exceed the NRWQC for lead in freshwater; however, lead concentrations in two of the samples are below the WQS for freshwater.

The elevated lead concentrations detected in sediment and surface water samples may be attributable to elevated lead levels in surface soils in the offsite investigation area. The surface water samples were not filtered; the lead may therefore be associated with suspended soil particles in the samples. Caprock groundwater does not discharge to the watercress farm area (see discussion in Section 3.8); the elevated lead concentrations are therefore not likely to be related to the 1971 MOGAS release.

4.2 SUBSURFACE SOIL

Subsurface soil samples were collected at 26 offsite direct-push boring locations (B-01 through B-26) during 11–22 June 1998, and at four offsite HSA boring locations (B-27 through B-30) during 6–10 July 1998. All subsurface soil samples were analyzed for the following constituents:

- TPH-gasoline and TPH-diesel by EPA SW 846 Method 8015B
- VOCs and SVOCs by CLP OLM 03.1
- Lead by CLP ILM 04.0

Detected concentrations above the MRLs are shown in Figure 4-3; all detected concentrations are summarized in Table 4-4. Complete data are presented in Appendix I.

Subsurface Soil Screening Criteria. Chemical concentrations detected in the subsurface soil samples are screened against the same criteria used for the surface soil samples, i.e., DOH Tier 1 action levels and EPA Region IX residential PRGs (see Section 4.1.1).

TPH Results. TPH-gasoline was detected in one sample, which was collected at 18.8–19.8 feet bgs in boring B-14 (located west of the Oshita watercress farm area). The detected TPH-gasoline concentration (1.5 mg/kg) is slightly above the MRL (1.4 mg/kg) and well below the DOH Tier 1 action level (2,000 mg/kg). TPH-diesel was not detected at concentrations above the MRL in any of the subsurface soil samples.

VOC Results. VOCs were detected at concentrations above the MRL in 24 subsurface soil samples. Low concentrations of 1,2-DCA were detected in two samples: one from boring B-07 at 17–18 feet bgs (3.76 µg/kg), and one from boring B-08 at 19–20 feet bgs (2.58 µg/kg). Acetone, 2-butanone, and carbon disulfide were generally detected at concentrations similar to those detected in surface soil and sediment samples; however, acetone was detected at relatively higher concentrations in samples from borings B-15, B-21, B-27, and B-29. These compounds are common laboratory reagents. Benzene and toluene were not detected in any of the subsurface soil samples. Ethylbenzene, total

xylenes, and trimethylbenzenes were detected only in samples collected from borings B-29 and B-30. All detected VOC concentrations are below the EPA Region IX residential PRG values.

SVOC Results. Thirty-one samples contained SVOCs (including PAHs) at concentrations above MRLs. HMW PAHs, such as benzo(a)pyrene, benzo(b)fluoranthene, and benzo(g,h,i)perylene, were detected at very low levels in soil samples from several borings (B-06, B-14, B-17, and B-27 through B-29). Lighter-end SVOCs and PAHs, such as 2-nitrophenol, phenol, 2-methylnaphthalene, and naphthalene, were detected at low levels in soil samples from borings B-15, B-17, and B-29 through B-30. Phthalates were also detected at very low concentrations throughout the investigation area. No SVOCs were detected at concentrations above the screening criteria.

Lead. Lead concentrations above the MRL were detected in 42 subsurface soil samples. Concentrations ranged from less than 1 to 3 mg/kg, well below the EPA Region IX (1998) residential PRG (400 mg/kg).

4.3 GROUNDWATER

The Phase II RI groundwater sampling program comprised two separate sampling rounds. In round one, samples were collected during June–July 1998 from the following sites:

- 12 offsite microwells
- 4 newly installed offsite monitoring wells
- 21 onsite monitoring wells

Subsurface soil and microwell groundwater sampling results were used to select locations for the four new permanent monitoring wells installed in the offsite area. Caprock groundwater samples were collected in two sampling rounds from the new offsite wells, and from 21 previously existing onsite wells.

In round two, samples were collected during April–May 1999 from the following sites:

- 4 offsite monitoring wells
- 21 onsite monitoring wells
- 3 offsite artesian wells

To evaluate the potential impact of the irrigation water on surface water quality in the watercress patches, filtered and unfiltered groundwater samples were collected from three of the offsite artesian wells that irrigate the watercress farms. The artesian well sampling data were also used to confirm that caprock groundwater contaminants have not impacted the confined basal aquifer.

All groundwater samples were analyzed for the following constituents:

- TPH-gasoline, TPH-kerosene, and TPH-diesel by EPA SW 846 Method 8015B
- VOCs and SVOCs by CLP OLM 03.1 (Round One), and EPA SW 846 Methods 8260B and 8270, respectively (Round Two)
- Metals by CLP ILM 04.0
- Hydrogeochemical parameters by the methods listed in Table 2-6

Table 4-4: Organic Compounds and Lead Concentrations in Subsurface Soil, Phase II RI, Ewa Junction Fuel Drumming Facility

Analyte	EPA Region IX Residential Soil PRG	sample depth (feet bgs)	Offsite Sampling Location																																											
			B-01	B-02	B-03	B-04	B-05	B-06	B-07	B-08	B-09	B-10	B-11	B-12	B-13	B-14	B-15	B-15	B-16	B-17	B-18	B-18 Duplicate	B-19	B-20	B-21	B-22	B-23	B-24	B-24 Duplicate	B-25	B-25 Duplicate	B-26	B-27	B-27	B-27	B-28	B-28	B-28	B-29	B-29 Duplicate	B-29	B-30	B-30	B-30		
			18.0-19.0	19.5-20.5	10.5-11.5	21.5-22.5	23.0-24.0	21.0-22.0	17.0-18.0	19.0-20.0	20.5-21.5	19.0-20.0	15.5-16.5	11.0-12.0	19.0-20.0	18.8-19.8	4.0-5.0	6.0-7.0	23.0-24.0	19.0-20.0	21.0-22.0	21.0-22.0	19.0-20.0	25.0-26.0	7.0-8.0	27.0-28.0	12.0-13.0	7.0-8.0	7.0-8.0	7.5-8.5	7.5-8.5	6.0-7.0	8.3-9.3	21.0-22.0	25.0-26.0	17.0-18.0	28.5-29.5	31.0-32.0	15.0-16.0	18.0-18.0	16.0-18.0	21.0-22.0	21.0-22.0	23.0-24.0	25.0-26.0	
TPH-Gasoline and -Diesel (mg/kg) by EPA SW 346 Method 8015B																																														
C08-C11 (gasoline range)	2,000 *		1.5U	1.3U	1.5U	1.4U	1.4U	1.5U	1.5U	1.5U	1.5U	1.4U	1.5U	1.4U	1.4U	1.5	1.5U	1.4U	1.3U	1.6U	1.6U	1.5U	1.3U	1.3U	1.6U	1.4U	1.6U	1.5U	1.5U	1.5U	1.5U	1.4U	1.5U	1.3U	1.4U	1.5U	1.3U	1.5U	1.5U	15U	30U	1.8U	1.6U	1.6U	1.6U	1.6U
Volatiles (µg/kg) by CLP OLM 03.1																																														
Acetone	1,400,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	30.92	24.47J	15.66	18.45	26.59	13.85U	9.46J	208.6	254.4J	49.11	13.67J	15.62U	26.2	55.85	37.3	155.6	14.28U	64.85	15.15U	19.43	14.88U	15.46U	8.86J	782.2J	12.85U	14.35U	15.36UJ	27.85	14.79U	397	153.6UJ	18,040J	16.1U	16.42UJ	48.82J	16.08U	
2-Butanone	6,900,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	14.99U	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89U	24.88	43.8J	13.51U	15.87U	15.62U	15.15U	13.16U	13.16U	15.87U	14.28U	8.78J	15.15U	15.15U	14.88U	15.46U	14.18U	15.2U	12.85U	14.35U	15.36U	12.92UJ	14.79UJ	147.2	153.6U	150.4U	16.1U	16.42U	16.37U	16.08U	
Carbon disulfide	350,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15UJ	14.6UJ	14.99UJ	15.48UJ	14.24UJ	14.64UJ	14.16UJ	13.85UJ	13.89U	14.7U	16.18J	13.51U	15.87U	15.62U	15.15U	13.16U	13.16U	15.87U	14.28U	16.63	15.15U	15.15U	14.88U	15.46U	14.18U	4.26J	12.85U	14.35U	15.36U	12.92UJ	14.79UJ	77.04U	153.6U	150.4U	16.1U	16.42U	16.37U	16.08U	
1,2-DCA	340		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	3.75J	2.58J	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89U	14.7U	14.08UJ	13.51U	15.87U	15.62U	15.15U	13.16U	13.16U	15.87U	14.28U	15.62U	15.15U	15.15U	14.88U	15.46U	14.18U	15.2U	12.85U	14.35U	15.36U	12.92UJ	14.79U	77.04U	153.6U	150.4U	16.1U	16.42U	16.37U	16.08U	
Ethylbenzene	230,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	14.99U	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89U	14.7U	14.08UJ	13.51U	15.87U	15.62U	15.15U	13.16U	13.16U	15.87U	14.28U	15.62U	15.15U	15.15U	14.88U	15.46U	14.18U	15.2UJ	12.85U	14.35U	15.36U	12.92U	14.79U	77.04U	2.635	58.26J	16.1U	16.42U	16.37U	16.08U	
1,2,4-Trimethylbenzene	51,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	14.99U	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89UJ	14.7UJ	14.08UJ	13.51UJ	15.87UJ	15.62UJ	15.15UJ	13.16UJ	13.16UJ	15.87UJ	14.28U	15.62UJ	15.15UJ	15.15U	14.88U	15.46U	14.18U	15.20U	12.85U	14.35U	15.36U	12.92U	14.79U	77.04U	265.4J	161J	16.1U	9.3J	1.66J	16.08U	
1,3,5-Trimethylbenzene	21,000		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	14.99U	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89U	14.7UJ	14.08UJ	13.51UJ	15.87UJ	15.62UJ	15.15UJ	13.16UJ	13.16UJ	15.87UJ	14.28U	15.62UJ	15.15UJ	15.15U	14.88U	15.46U	14.18U	15.20U	12.85U	14.35U	15.36U	12.92U	14.79U	77.04U	149.9J	237J	16.1U	32.23	3.31J	16.08U	
Xylenes, total	ns		15.41UJ	12.97UJ	15.15UJ	14.35UJ	14.35U	15.15U	14.6U	14.99U	15.48UJ	14.24U	14.64U	14.16U	13.85U	13.89UJ	14.7UJ	14.08UJ	13.51UJ	15.87UJ	15.62UJ	15.15UJ	13.16UJ	13.16UJ	15.87UJ	14.28U	15.62UJ	15.15UJ	15.15U	14.88U	15.46U	14.18U	15.2UJ	12.85U	14.35U	15.36U	12.92U	14.79U	77.04U	3,768J	150.4U	16.1U	16.42U	16.37U	16.08U	
SVOCs (µg/kg) by CLP OLM 03.1																																														
Benzo(a)pyrene	56		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	14J	483.9U	464.1U	444.7U	20.18J	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	
Benzo(b)fluoranthene	560		508.5U	428U	500U	473.4U	473.4U	17.13J	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Benzo(g,h,i)perylene	ns		508.5U	428U	500U	473.4U	473.4U	18.42J	481.8U	494.8U	510.8UJ	470.1UJ	483.2UJ	467.4UJ	457.1UJ	455.2UJ	483.9UJ	464.1UJ	444.7UJ	79.93J	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	18.04J	330U	24.57J	330U	330U	41.63J	330U	330U	330U	330U	330U		
BEHP	320,000		508.5U	428U	500U	473.4U	473.4U	28.81J	20.24J	26.05J	29.63J	57.32J	483.2U	467.4U	457.1U	54.32J	23.44J	22.84J	18.34J	38.48J	513.2U	503UJ	441.2UJ	434.8R	21.78J	474.1U	517.2U	499.2R	499.2UJ	29.72J	510U	19.36J	12.6J	330U	35.7J	35.85J	30.92J	330U	15.24J	330U	12.12J	330U	330U	44.28J	330U	
Di-n-butylphthalate	5,500,000		43.13J	33.8J	500U	473.4U	473.4U	43.66J	48.27J	481.8U	494.8U	510.8U	47.16J	483.2U	44.96J	457.1U	61.08J	483.9U	464.1U	46.88J	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	45.38J	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Diethylphthalate	44,000,000		508.5U	428U	500U	473.4U	473.4U	24.3J	20.95J	494.8U	510.8U	470.1U	483.2U	20.48J	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	30.51J	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Hexachlorobenzene	280		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
2-Methylnaphthalene	ns		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
2-Nitrophenol	ns		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Naphthalene	55,000		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	520.5U	513.2U	503UJ	441.2UJ	434.8R	522.2UJ	474.1U	517.2U	499.2R	499.2UJ	491.1UJ	510U	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Phenol	33,000,000		508.5U	428U	500U	473.4U	473.4U	500U	481.8U	494.8U	510.8U	470.1U	483.2U	467.4U	457.1U	455.2U	483.9U	464.1U	444.7U	18.66J	513.2U	503UJ	441.2UJ	434.8U	522.2UJ	474.1UJ	517.2UJ	498.5U	499.2UJ	491.1UJ	510UJ	468.1U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U	330U		
Pyrene	1,500,000		508.5U	428U	500U	473.4U																																								

The hydrogeochemical data (presented in the sample analysis summary, Appendix I) were used to evaluate natural attenuation processes at the EJFDF (see Section 5.4.2). The hydrogeochemical constituents are not contaminants.

Groundwater Screening Criteria. Chronic marine WQSs and DOH Tier 1 action levels for groundwater (drinking water source not threatened and rainfall less than 200 centimeters per year) are used as screening criteria for VOCs, SVOCs, and metals in groundwater. Where both a WQS and a Tier 1 action level are established for a given analyte and the two values differ, the lower of the two values is used as the screening criterion. (No WQSs or DOH Tier 1 groundwater action levels are established for TPH.) Safe Drinking Water Act (SDWA) maximum contaminant levels (MCLs) are used as screening criteria for groundwater samples collected from the artesian wells that tap the confined basal aquifer in the offsite area. The groundwater screening criteria are described in more detail in Section 8.1.4.

Detected Groundwater Concentrations. Groundwater sampling results from round one (June–July 1998) and round two (April–May 1999) are summarized in Table 4-5 and Table 4-6, respectively. Complete groundwater data for both sampling rounds are presented in Appendix I. The figures listed below illustrate spatial and temporal trends in the concentrations of BTEX, 1,2-DCA, and lead, which were identified as indicator chemicals (ICs) for the caprock groundwater (see Section 5.2).

Total BTEX concentrations detected in EJFDF in caprock groundwater are presented in the following:

- Figure 4-4 (Phase I RI sampling: August 1994)
- Figure 4-5 (Phase II RI round-one sampling: June–July 1998)
- Figure 4-6 (Phase II RI round-two sampling: April–May 1999)

Total 1,2-DCA concentrations detected in EJFDF caprock groundwater are shown in the following:

- Figure 4-7 (Phase I RI sampling: August 1994)
- Figure 4-8 (Phase II RI round-one sampling: June–July 1998)
- Figure 4-9 (Phase II RI round-two sampling: April–May 1999)

Total lead concentrations detected in EJFDF caprock groundwater are shown in the following:

- Figure 4-10 (Phase II RI round-one sampling: June–July 1998)
- Figure 4-11 (Phase II RI round-two sampling: April–May 1999)

TPH-gasoline concentrations detected in EJFDF caprock groundwater are shown in the following:

- Figure 4-12 (Phase II RI round-two sampling: April–May 1999)

Table 4-5: Organic Compounds and Metal Concentrations in Groundwater, June–July 1998, Phase II RI, Ewa Junction Fuel Drumming Facility

Analyte	Chronic Marine WQS	Tier 1 Action Level ^a	sample depth (feet bgs)	Onsite Sampling Locations																				Offsite Sampling Locations																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			
				MW-1	MW-2	MW-3	MW-4	MW-4 Duplicate	MW-6	MW-7	MW-8	MW-9	MW-10	MW-11	MW-12	MW-13	MW-14	MW-15	MW-16	MW-17	MW-18	MW-19	MW-19 Duplicate	MW-20	MW-21	MW-22	MW-23	MW-24	MW-25	MW-26	MI-1	MI-1 Duplicate	MI-2	MI-2 Duplicate	MI-3	MI-4	MI-5	MI-6	MI-7	MI-8	MI-9	MI-10	MI-11	MI-12																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
				92.0	79.0	24.0	27.7	27.7	28.5	31.0	25.0	26.3	27.3	83.5	35.0	28.0	90.0	57.0	26.0	33.5	19.5	55.5	55.5	81.0	70.0	61.0	22.5	32	31.0	27.0	19.3	19.3	11.6	11.6	20.3	17.3	20.2	19.8	18.9	22.2	18.6	26.0	17.0	9.2																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																															
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Acetone	ns	610		10UJ	10UJ	10U	10UJ	10UJ	10UJ	10U	20.97J	10U	10UJ	10UJ	10UJ	17.27J	10UJ	15.96J	10U	10U	10U	10U	10UJ	18.9J	21.98J	10UJ	10UJ	36.65J	10UJ	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	

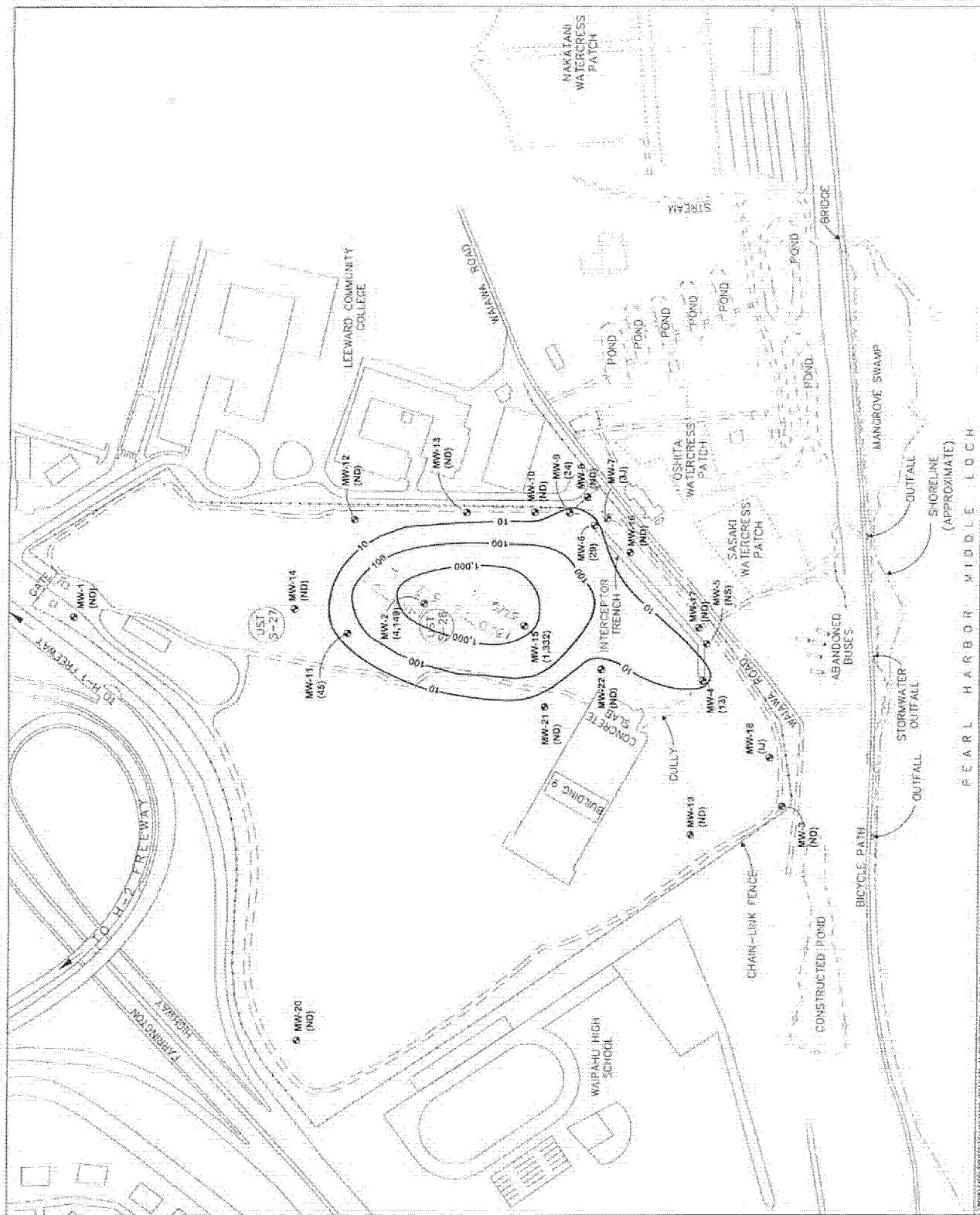
Table 4-6: Organic Compounds and Metal Concentrations in Groundwater, April–May 1999, Phase II RI, Ewa Junction Fuel Drumming Facility

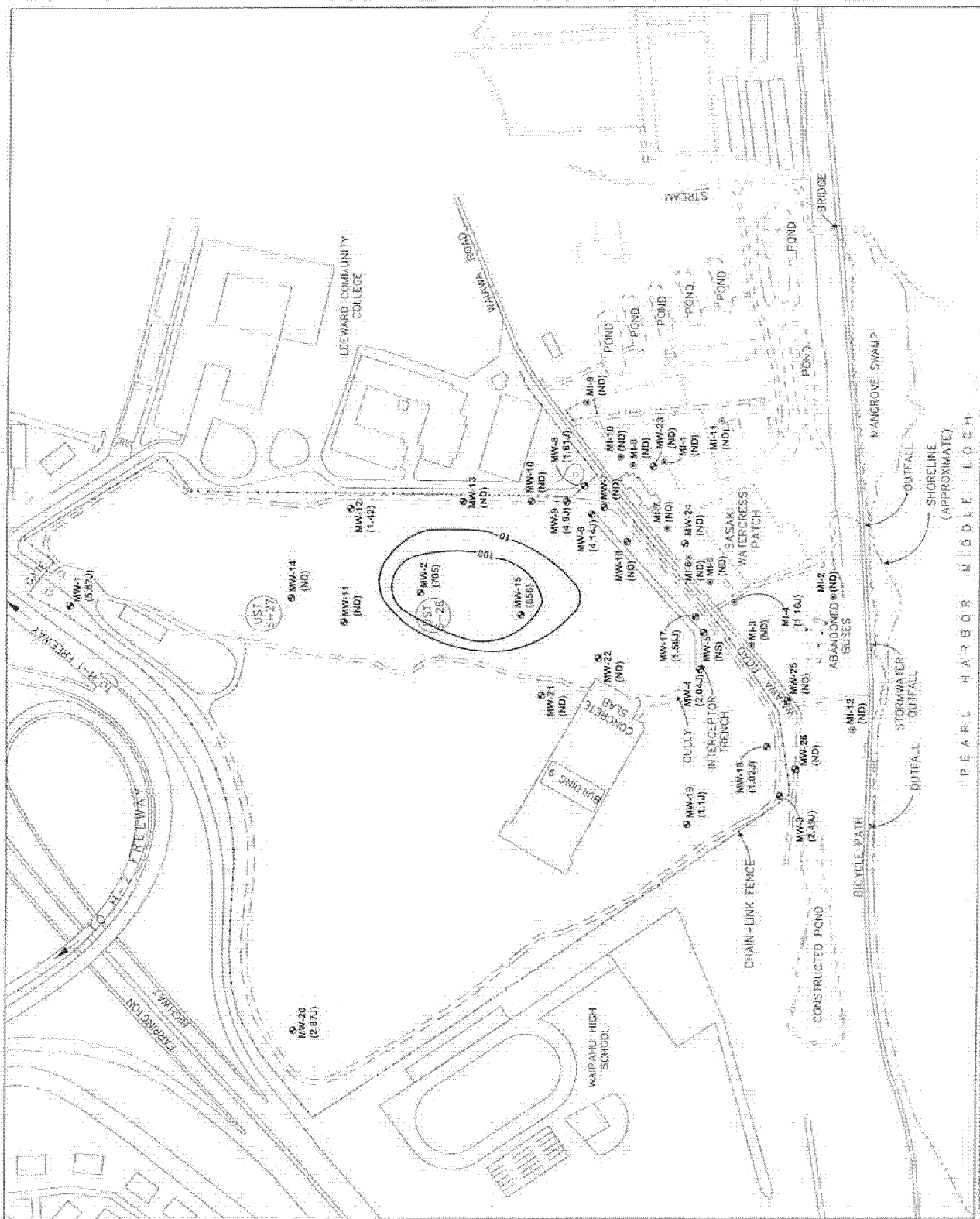
Analyte	Chronic Marine WQS	Tier 1 Action Level ^a	sample depth (feet bgs)	Onsite Sampling Locations																				Offsite Sampling Locations						Artesian Well (Basal Aquifer) Sampling Locations								
				MW-1	MW-2	MW-3	MW-4	MW-6	MW-7	MW-7 Duplicate	MW-8	MW-9	MW-10	MW-11	MW-12	MW-13	MW-14	MW-15	MW-15 Duplicate	MW-16	MW-17	MW-18	MW-19	MW-20	MW-21	MW-22	MW-23	MW-24	MW-25	MW-26	MW-26 Duplicate	FW-2	FW-2 Filtered	FW-3	FW-3 Filtered	FW-5	FW-5 Filtered	
				92.0	79.0	24.0	27.7	28.5	31.0	31.0	25.0	26.3	27.3	83.5	35.0	28.0	90.0	57.0	57.0	26.0	33.5	19.5	55.5	81.0	70.0	61.0	22.5	32	31.0	27.0	27.0	0.0	0.0	0.0	0.0	0.0	0.0	
TPH-Gasoline, -Kerosene (µg/L) by EPA SW 846 Method 8015B																																						
C08-C11 (gasoline range)	ns	ns		100U	950	100U	720	110	150	120	100U	140	100U	240	100U	100U	100U	1,100	1,100	100U	250	100U	100U	100U	100U	100U	100U	100U	100U	100U	100U	100U	100U	—	100U	—	100U	—
C11-C14 (Kerosene range)	ns	ns		0.26U	1.2	0.24U	2.8	0.26U	0.32	0.25U	0.25U	0.25U	0.26U	0.72	0.27U	0.26U	0.25U	1.3	1.2	0.26U	0.49	0.25U	0.26U	0.26U	0.25U	0.25U	0.25U	0.25U	0.26U	0.26U	0.26U	0.26U	0.26U	—	0.25U	—	0.25U	—
Volatiles (µg/L) by EPA SW 846 8260B																																						
Acetone	ns	610		10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	87	10U	10U	10U	10U	—	10U	—	10U	—	
Benzene	ns	1,700		1U	440U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	300	280	1U	1U	1U	1U	1U	1U	6.3	4.5	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
Carbon disulfide	ns	ns		10U	100U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	—	10U	—	10U	—	
1,2-DCA	ns	ns		1U	10U	1U	1U	1U	1U	1U	1U	1U	2.2	1U	1U	1.5	13	15	5.3	5.3	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
Ethylbenzene	ns	140		1U	60U	1U	2.8	1.5	1.3	1.5	1U	3.3U	1U	1U	1U	1U	75	76	1U	1U	1U	1U	1U	1U	3	2	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
Toluene	2,100	2,100		1U	39	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	5.6	5.7	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
1,2,4-Trimethylbenzene	ns	ns		1U	7.9U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
1,3,5-Trimethylbenzene	ns	ns		1U	1.2U	1U	1.7	1U	1U	1U	1U	1U	1U	1.7	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	1U	—	1U	—	1U	—	
Xylenes, total	ns	10,000		2U	41.1U	2U	2U	2U	2U	2U	2U	2U	2U	2U	2U	2U	5.4	5.4	2U	2U	2U	2U	2U	2U	1.2	2U	2U	2U	2U	2U	2U	2U	—	2U	—	2U	—	
SVOCs (µg/L) by EPA SW 846 8270																																						
Benzoic acid	ns	ns		60U	1.7U	50U	51U	51U	50U	50U	50U	48U	50U	2.1U	52U	51U	50U	1.9U	50U	51U	52U	51U	50U	54U	52U	1.4U	50U	53U	53U	51U	1U	51U	—	62U	—	52U	—	
BEHP	ns	ns		9.9U	10U	9.9U	10U	14	9.9U	9.9U	10U	9.6U	10U	10U	10U	10U	9.9U	10U	10U	12	10U	10U	9.9U	11U	10U	10U	0.49U	0.76U	0.45U	0.79U	0.64U	10U	—	12U	—	10U	—	
Diethylphthalate	ns	ns		1.8U	10U	9.9U	10U	10U	9.9U	9.9U	10U	9.6U	10U	10U	1.5U	10U	9.9U	10U	10U	10U	10U	10U	9.9U	1.6U	10U	10U	10U	11U	10U	10U	10U	10U	—	12U	—	10U	—	
Di-n-butylphthalate	ns	ns		9.9U	1.3U	9.9U	10U	10U	9.9U	9.9U	10U	9.6U	10U	10U	10U	10U	9.9U	10U	10U	10U	10U	10U	9.9U	11U	1.3U	1.3U	10U	11U	10U	10U	10U	10U	—	12U	—	10U	—	
2-Methylnaphthalene	ns	ns		9.9U	5.3U	9.9U	21	10U	9.9U	9.9U	10U	0.61	10U	10U	10U	10U	9.9U	16	17	10U	10U	10U	9.9U	11U	10U	10U	10U	11U	10U	10U	10U	10U	—	12U	—	10U	—	
Naphthalene	ns	770		9.9U	12	9.9U	10U	10U	9.9U	9.9U	10U	9.6U	10U	10U	10U	10U	9.9U	8.6U	9U	10U	10U	10U	9.9U	11U	10U	10U	10U	11U	10U	10U	10U	10U	—	12U	—	10U	—	
Phenol	ns	ns		9.9U	15	9.9U	4.7U	7.6U	5.3U	4.9U	9.6U	9.6U	12	22	1U	1.6U	15	20	22	4.8U	3.6U	6.5U	29	11U	6.2U	13	10U	11U	10U	10U	10U	10U	—	12U	—	10U	—	
General Metals (µg/L) by CLP ILM 04.0																																						
Aluminum	ns	ns		334.3U	18.4U	30.79	13.0U	13.0U	71.65	112.45	13.0U	13.0U	13.0U	83.82	34.6U	35.5U	183.53	17.6U	13.0U	31.34	21.82	24.09	127.05	183.5U	13.0U	271.50	13.0U	13.0U	13.32	13.0U	13.0U	13.0U	13.0U	13.0U	13.0U	69.3U	13.0U	13.0U
Antimony	ns	ns		10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	10U	23.36U	10U	
Arsenic	36	ns		0.7U	1.28	0.7U	1.08U	0.7U	1U	0.7U	0.7U	1.36U	0.7U	1.03U	0.7U	1.4U	1.1	1.25	0.945U	0.7U	1.13U	1.07U	0.7U	0.7U	0.7U	0.78U	0.8U	1.9U	1.37U	0.7U	1.34	0.7U	0.7U	0.76	0.7U	0.7U		
Barium	ns	ns		40.69	114.21	9.096	167.34	53.67	16.04	18.78	15.79	12.72	14.27	75.09	17.22	12.97U	33.78	223	223	29.34	20.59	10.35	18.22	14.79	28.52	42.97	10.53	13.19	7.9U	15.28	14.57	84.17	83.98	31.83	31.58	15.81	17.86	
Beryllium	ns	ns		0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.20U	0.15U	0.15U	0.41U	0.15U	0.15U	0.15U	0.15U	0.24U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.15U	0.16U	0.15U	0.15U	0.15U	0.15U		
Boron	ns	ns		953.98	801.05	539.51	642.50	597.55	699.42	795.42	776.18	612.13	469	1,380.27	913.42	1,020	1,621.59	713.19	715.03	617.55	521.62	719.91	512.84	408.34	747.18	752.00	674.77	709.68	535.01	529	575.03	116.6U	122U	169.05	174.6	186.78	183.59	
Cadmium	9.3	9		1.1U	1.0U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	1.28U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	0.74U	1.07U	0.74U	0.74U	1.69U	0.74U		
Chromium	50	ns		8.15U	3.3U	5.99U	3.3U	3.3U	17.05U	22.87U	3.3U	3.3U	3.3U	3.3U	3.3U	3.3U	4.6U	3.3U	3.3U	3.3U	3.3U	3.3U	7.6U	6.23U	36.53	18.0U	3.3U	9.8U	3.3U	3.3U	3.3U	3.3U	3.3U	3.3U	3.3U	3.3U		
Cobalt	ns	ns		5.0U	9.3U	1.6U	4.84	1.6U	1.6U	1.6U	1.6U	2.7	1.6U	1.6U	2.10U	1.6U	2.46	9.89U	8.89U	9.93	12.14	1.6U	1.6U	1.6U	1.6U	8.08U	1.6U	1.6U	1.6U	1.6U	1.6U	1.6U	1.6U	1.6U	1.6U	1.6U		
Copper	2.9	ns		3.17	2.4U	2.4U	2.4U	2.4U	2.4U	2.50	2.4U	2.4U	2.4U	2.4U	2.4U	2.4U	2.4U	2.68U	2.67U	2.4U	2.4U	2.4U	2.4U															

LEGEND	
Monitoring Well Location (MW #)	
Total BTEX Concentration in $\mu\text{g/L}$	
100	Total BTEX isopleth ($\mu\text{g/L}$)
	Paved Road
	Dirt Road
	Fence
	Edge of Mangrove Swamp
	Watercress Patch
	Pond or Stream
NOTES	
ND	Below Quantitation Limit ($<10 \mu\text{g/L}$)
NS	Not Sampled
J	Estimated Concentration
SOURCE	
Phase I RI Report (Ogden 1996)	



Figure 4-4
Total BTEX Concentrations
in Groundwater, August 1994 (Phase I RI)
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii





LEGEND

- Monitoring Well Location (MW-#)
- Total BTX Concentration in $\mu\text{g/L}$
- Total BTX Isopleth ($\mu\text{g/L}$)
- Paved Road
- Dirt Road
- Fence
- Edge of Mangrove Swamp
- Watercress Patch
- Pond or Stream

NOTES

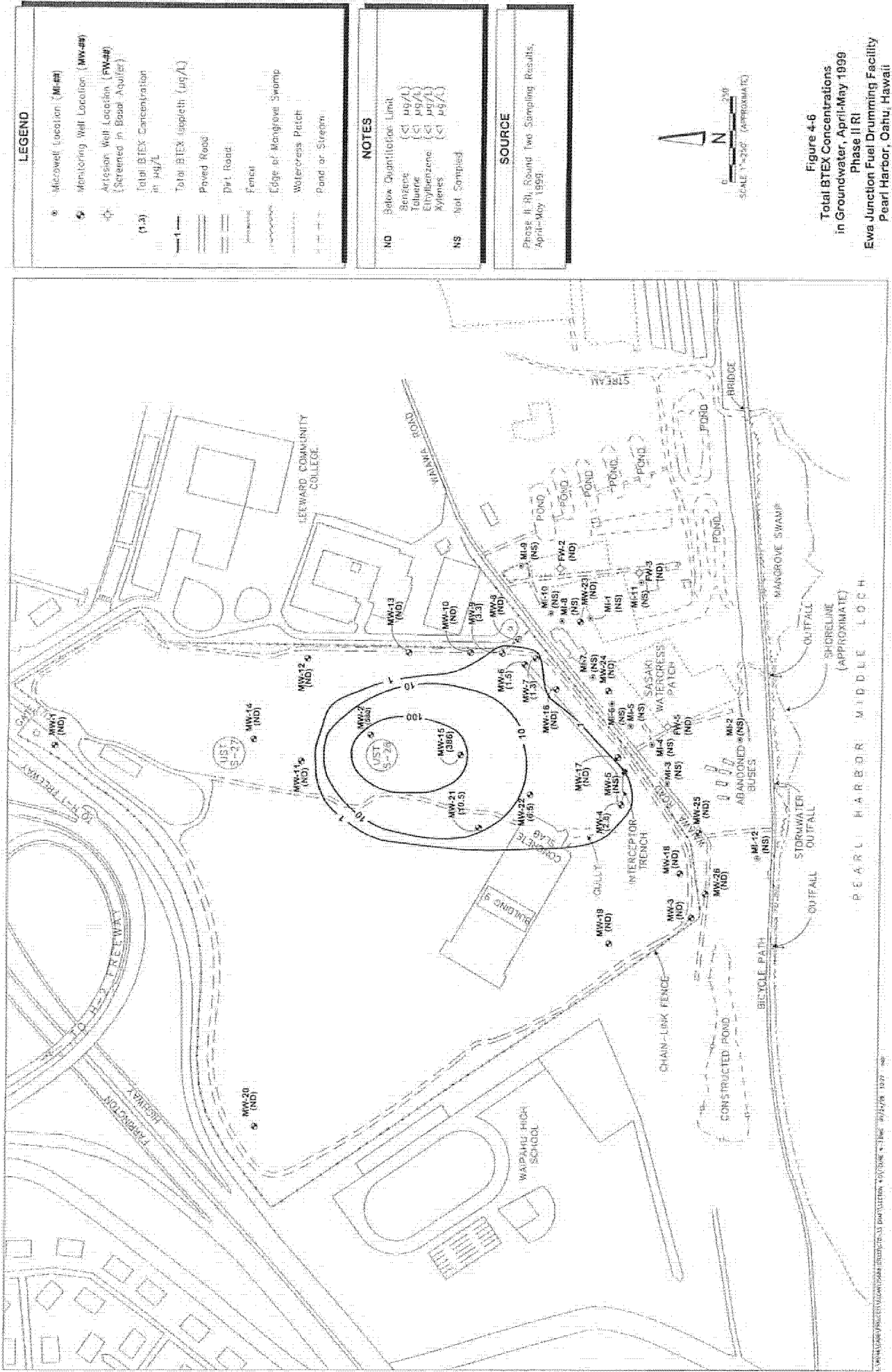
- ND: Below Quantitation Limit ($<0.1 \mu\text{g/L}$)
- NS: Not Sampled
- J: Estimated Concentration

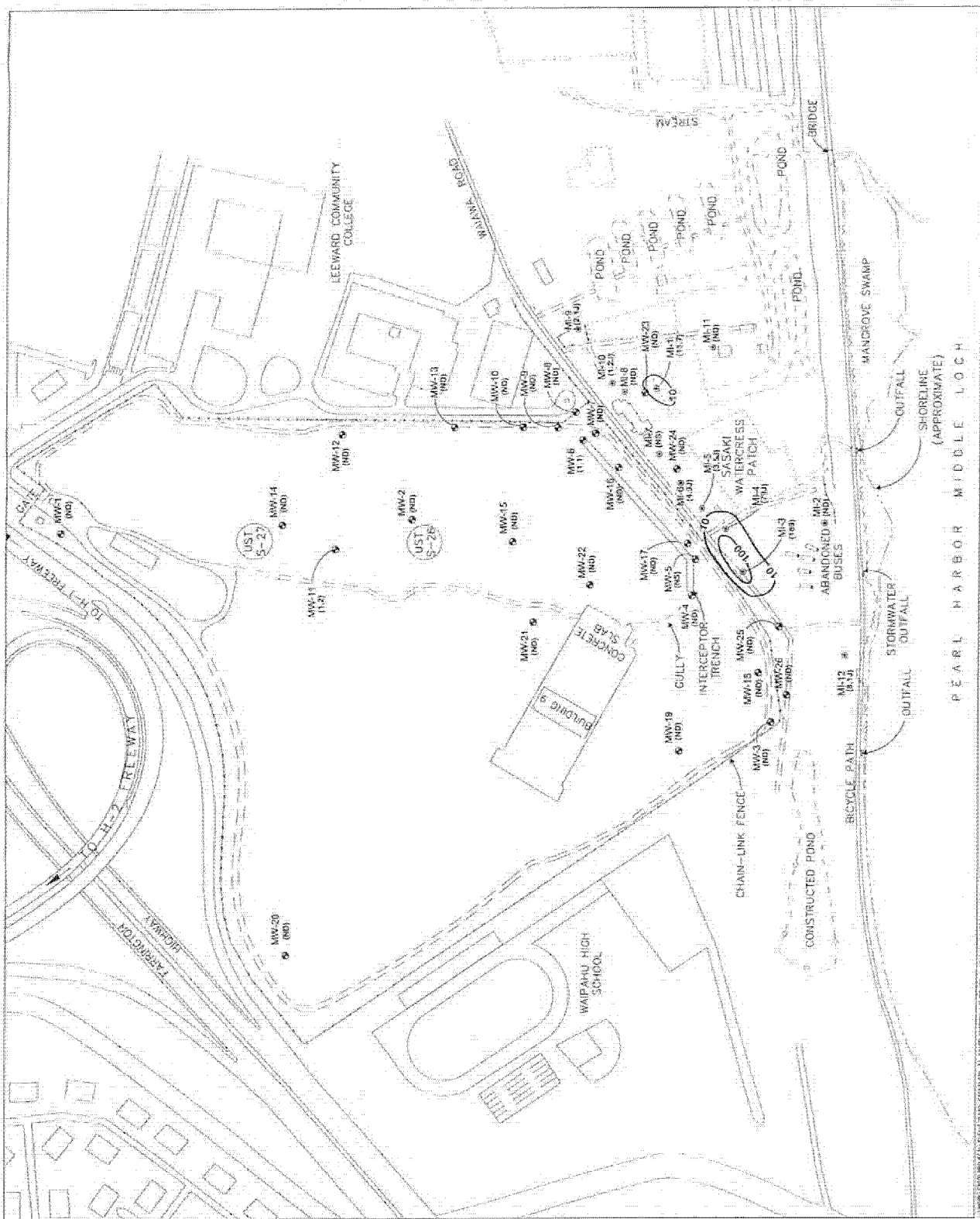
SOURCE

Phase II RI, Round One Sampling Results, June-July 1998.

SCALE 1"=200' (APPROXIMATE)

Figure 4-5
Total BTX Concentrations
in Groundwater, June-July 1998
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii





LEGEND	
•	Microtremor Location (MI-#)
•	Monitoring Well Location (MW-#)
(13.7)	Total Lead Concentration in µg/L
—10—	Lead Isopleth (µg/L)
—	Paved Road
—	Dirt Road
—	Fence
—	Edge of Mangrove Swamp
—	Waterless Patch
—	Pond
NOTES	
ND	Below Quantitation Limit (<10 µg/L)
NS	Not Sampled
J	Estimated Concentration
SOURCE	
Phase II RI Round One Sampling Results, June-July 1998	



Figure 4-10
Lead Concentrations
in Groundwater, June-July 1998
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

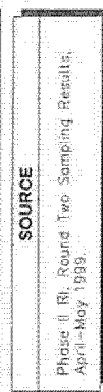
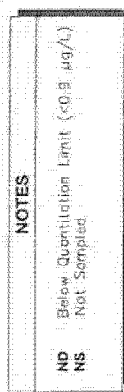
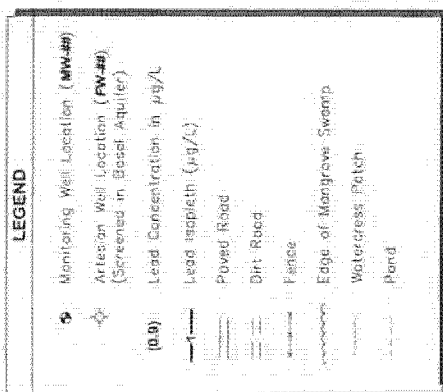
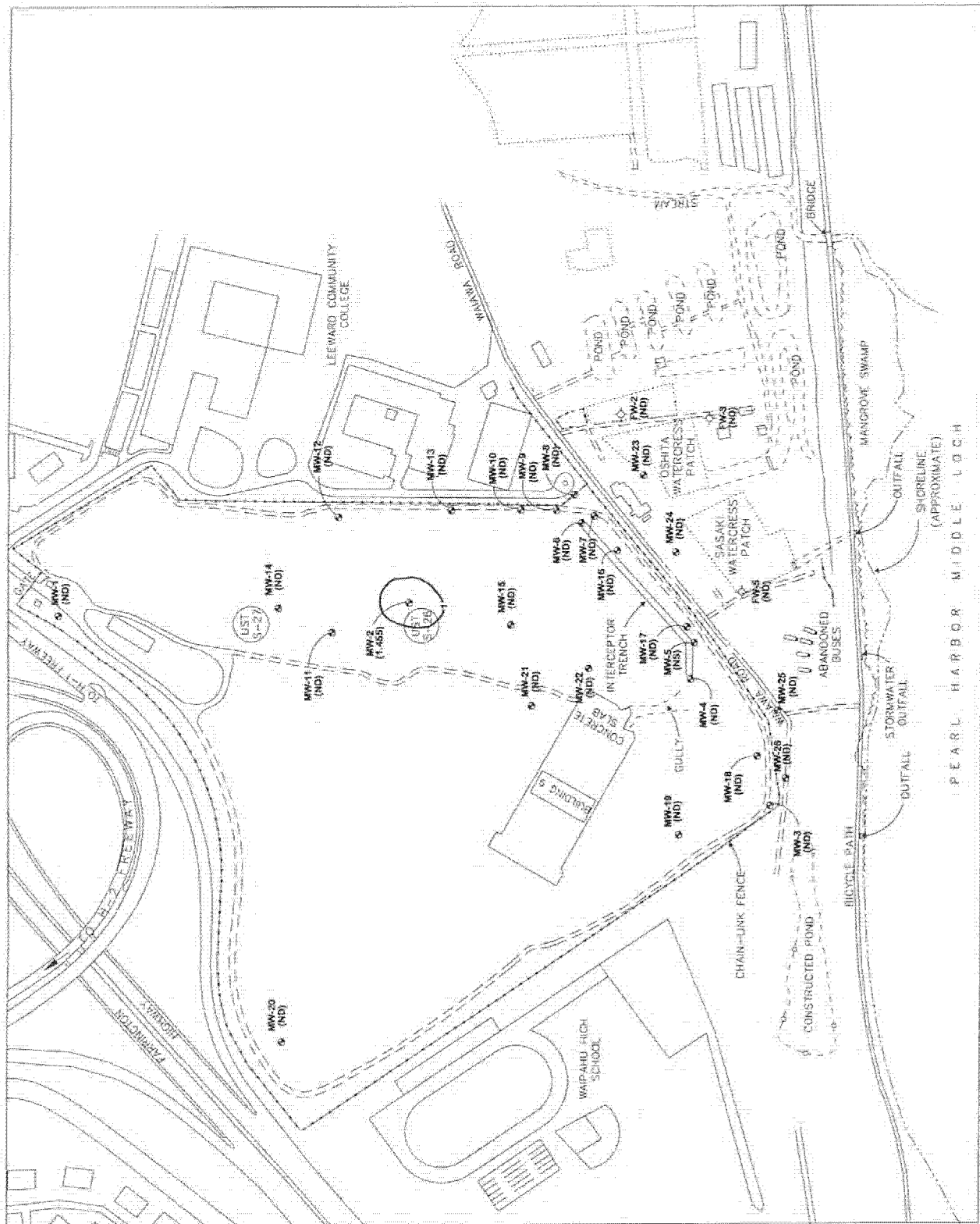


Figure 4-11
Lead Concentrations
in Groundwater, April-May 1999
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii



LEGEND	
Monitoring Well Location (MW-#)	
Artesian Well Location (PW-#)	
(Screened in Basal Aquifer)	
TPH-Gasoline Concentration in $\mu\text{g/L}$	
100	
1000	
10000	
Paved Road	
Dirt Road	
Fence	
Edge of Mangrove Swamp	
Watercress Patch	
Pond or Stream	

NOTES	
ND	Below Quantitation Limit ($<100 \mu\text{g/L}$)
NS	Not Sampled

SOURCE	
Phase II RI Round Two Sampling Results, April-May 1999	

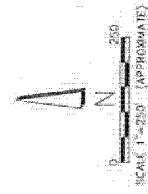
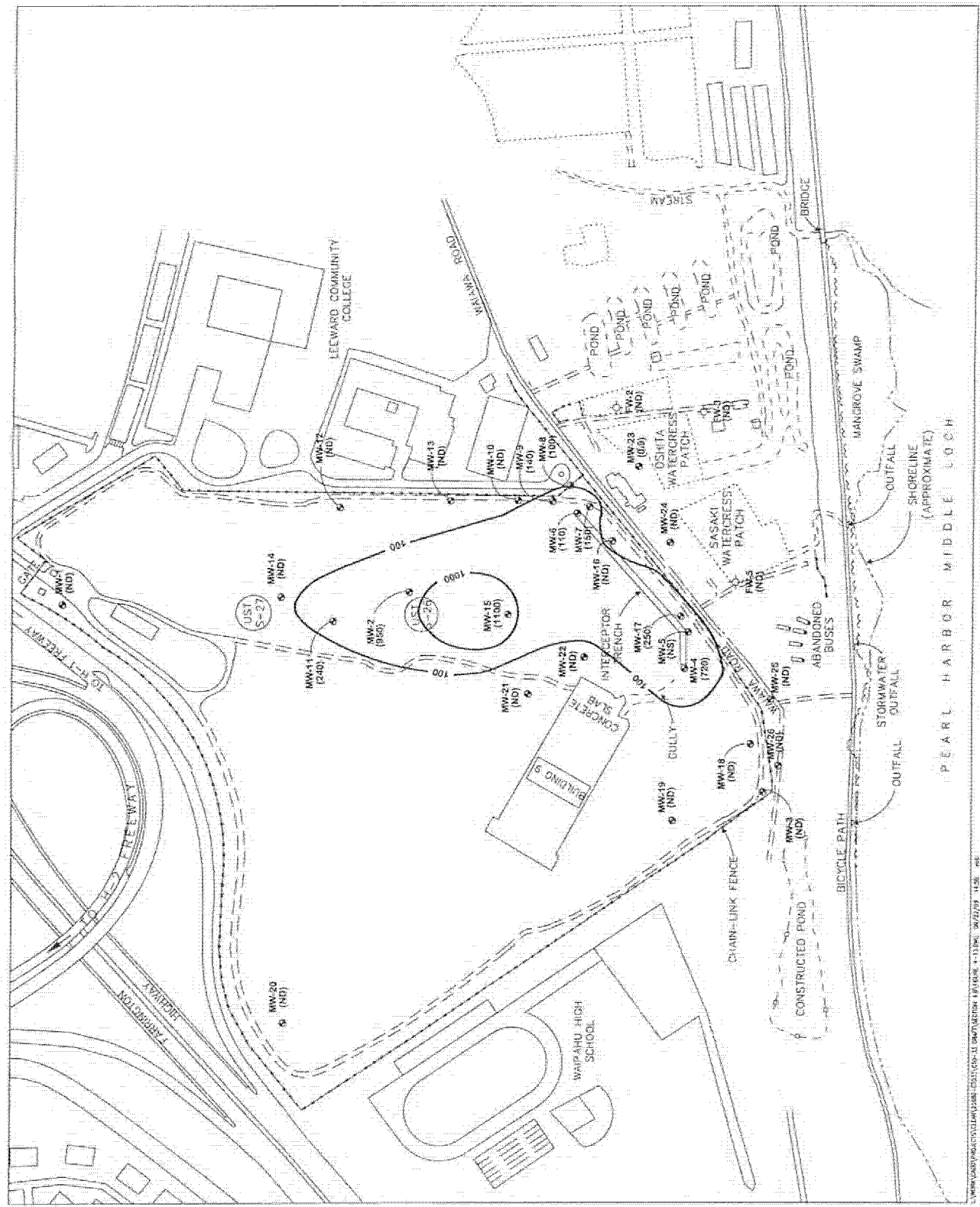


Figure 4-12
TPH-Gasoline Concentrations
in Groundwater, April-May 1999
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii



4.3.1 First-Round Sampling, June–July 1998

TPH Results. TPH was detected in only one of the groundwater samples collected during the first sampling round (TPH-gasoline at 5,400 µg/L in the MW-2 sample). TPH-gasoline concentrations were below the MRL in all other samples, as shown in Table 4-5. TPH-diesel and TPH-kerosene concentrations were below the MRL (0.26 µg/L) in all first round groundwater samples. All TPH data are presented in Appendix I.

VOC Results. Samples from 18 of the onsite monitoring wells, one offsite monitoring well, and three microwells contained VOC concentrations above the MRLs. No VOCs were detected at concentrations above WQSs or DOH Tier 1 action levels, as presented in Table 4-5.

BTEX. The highest total BTEX concentrations have historically been detected at MW-2 (which is located adjacent to UST S-26, the MOGAS release point) and MW-15 (which is located approximately 250 feet downgradient of UST S-26). Total BTEX concentrations detected at these two monitoring wells decreased significantly during the approximately 4 years between the Phase I RI and Phase II RI sampling events, as shown in Figure 4-4 and Figure 4-5. Total BTEX concentrations detected in July 1998 at MW-2 and MW-15 were 705.3 and 656.1 µg/L, respectively. No BTEX compounds were detected in offsite groundwater except in MI-4, where a very low toluene concentration (1.16 µg/L) was detected.

1,2-DCA. Changes in 1,2-DCA concentrations between August 1994 and June–July 1998 are shown in Figure 4-7 and Figure 4-8. In the area between USTs S-26 and S-27, 1,2-DCA concentrations decreased from greater than 10 µg/L to approximately 1 µg/L or less. However, the 1,2-DCA plume appears to have migrated slightly toward the southwest along and just south of the site boundary, where 1,2-DCA concentrations detected in offsite wells MW-25, MI-6, and MI-7 ranged from 1 to 6 µg/L.

Other VOCs. Acetone was detected in MW-9, MW-14, MW-16, MW-21, MW-22, and MW-25 at concentrations ranging from 15.96 µg/L to 36.65 µg/L. Carbon disulfide was detected in the sample from MW-8 (2.4 µg/L). Trimethylbenzenes were detected in the sample from MW-2.

SVOC Results. Thirty-one samples (including two duplicate samples) contain SVOCs and PAHs at concentrations above MRLs. No SVOCs were detected at concentrations above WQSs or DOH Tier 1 action levels.

BEHP. Elevated BEHP levels were reported for samples from four onsite monitoring wells (MW-1, MW-9, MW-16, and MW-20). As discussed below in Section 4.4, the elevated BEHP levels are attributed to laboratory contamination.

Metal Results

Lead. Lead concentrations detected in the two Phase II RI sampling rounds are shown in Figure 4-10. Lead was detected at concentrations above the MRL (1 µg/L) in two onsite monitoring well samples and in nine offsite microwell samples (including one duplicate sample).

Lead was detected at low concentrations (less than 1.2 µg/L) in two of the onsite monitoring well samples (from MW-6, located at the northeast end of the interceptor trench, and MW-11, located outside of the BTEX plume area, between UST-26 and UST-27).

Lead levels above the chronic marine WQS value (5.6 µg/L) were detected in samples collected from four of the twelve offsite microwells. The highest lead concentration (188.95 µg/L) was detected in

the sample from MI-3 (northwest of the Sasaki watercress patch). Lead was detected at 79.4 µg/L in the sample from MI-4 (approximately 100 feet northeast of MI-3). The lead concentrations detected at MI-1 (north of the Oshita watercress patch) and MI-12 (near the bicycle path) were 13.7 µg/L and 8.1 µg/L, respectively. Lead was not detected at concentrations above the MRL in any of the offsite (4-inch-diameter) monitoring well samples.

The elevated lead levels detected in the offsite microwell samples are most likely associated with suspended particulates. The groundwater samples were not filtered in the field or in the laboratory prior to analysis. The 1-inch microwells were difficult to develop; as a result, turbidity of the microwell groundwater samples was significantly higher than turbidity in the monitoring well groundwater samples. For example, the turbidity measured immediately before sample collection at MI-3 was 138 nephelometric turbidity units (NTUs), and the sample was described as "muddy brown." Monitoring well groundwater samples, on the other hand, were described as clear, and turbidity levels measured immediately prior to sampling were never more than 7.4 NTUs (turbidity of most monitoring well samples was even lower, near zero). Lead was detected at significant concentrations only in turbid samples from the microwells, and lead levels detected in the monitoring wells both on and off site are very low; therefore, the 1971 MOGAS release is not likely to be the source of lead detected in offsite groundwater samples during the first sampling round.

Other Metals. Metal concentrations above MRLs were detected in all 25 monitoring wells and in 11 of the 12 microwells. Copper, chromium, nickel, arsenic, and zinc were detected at concentrations above WQSS. Elevated copper, nickel, and zinc concentrations were detected in the samples from MW-1 and MW-19, both of which are outside the area impacted by the MOGAS release. MW-1 is located approximately 900 feet upgradient of UST S-26. MW-19 is located south of Building 9. Concentrations of these metals are lower in the wells downgradient of UST S-26, indicating that the elevated metals concentrations are not related to the MOGAS release. Elevated copper, chromium, nickel, arsenic, and zinc concentrations were also detected in the offsite microwells. These metal detections are likely to be due to the high suspended solids content (i.e., high turbidity) of the microwell samples. Concentrations of these metals detected in the (low-turbidity) offsite monitoring well samples were much lower.

4.3.2 Second-Round Sampling, May 1999

TPH Results. TPH-gasoline was detected in 11 samples (including two duplicate samples) collected from onsite monitoring wells; concentrations range from 100 to 1,100 µg/L (the MRL is 100 µg/L), as shown in Table 4-6 and Figure 4-12. The TPH-gasoline plume underlies approximately the same area as the BTEX plume. The first- and second-round groundwater TPH results show little correlation. The lack of correlation may indicate a problem with the first-round laboratory's TPH analyses. The second-round TPH results correlate well with the BTEX results; therefore, the second round TPH results are likely to represent actual field conditions.

TPH-middle distillates (kerosene) was detected in seven samples (including one duplicate sample) collected from the onsite monitoring wells; concentrations range from 0.3 to 2.8 µg/L. TPH-diesel concentrations are below the MRL. The TPH-kerosene distribution correlates well with the TPH-gasoline distribution; therefore, the kerosene-range hydrocarbons are likely to represent the heavier end of the MOGAS product, rather than a distinct contaminant source.

VOC Results. VOC concentrations above MRLs were detected in samples from 15 onsite monitoring wells. Acetone is the only VOC detected in offsite groundwater (at MW-24). No VOC concentrations are above chronic marine WQSS or DOH Tier 1 action levels, as shown in Table 4-6.

BTEX. As shown in Figure 4-6, maximum total BTEX concentrations were detected at monitoring wells MW-2 and MW-15 (total BTEX concentrations were 580.1 and 386 µg/L, respectively). A significant decrease in total BTEX concentrations occurred over the period between the first and second sampling rounds.

1,2-DCA. As shown in Figure 4-9 and Table 4-6, 1,2-DCA was detected in several onsite monitoring wells during round two. As in round one, 1,2-DCA concentrations slightly above the MRL were detected upgradient of the BTEX plume in MW-11 and MW-14. Although the 1,2-DCA concentration detected at MW-15 during round one is below the MRL (10 µg/L), the round-two concentration for MW-15 is 15 µg/L.

SVOC Results. SVOC concentrations above MRLs were detected in samples from 19 onsite monitoring wells and all four offsite monitoring wells. No SVOCs were detected at levels above their screening criteria. BEHP was detected at low levels in MW-6 and MW-16 (in the southeastern corner of the site), and at very low levels in the offsite monitoring wells. No HMW PAHs were detected during the second round. SVOC concentrations in the artesian well samples are below MRLs.

Metal Results

Lead. As shown in Figure 4-11 and Table 4-6, lead was detected at only one sampling location: MW-2 (1.455 µg/L). The detected lead concentration is well below the WQS. Lead was not detected in any of the artesian well groundwater samples.

Metal concentrations above MRLs were detected in all monitoring wells and artesian wells sampled during the second round. However, the pattern of metal detections indicates that the 1971 MOGAS release is not likely to be the source. Copper and zinc concentrations slightly exceed the WQS screening criteria in the sample from (upgradient) well MW-1. Copper was also detected at a concentration slightly above the WQS in the (downgradient) MW-23 sample. Copper and zinc concentrations detected within the core of the area impacted by the MOGAS release are below MRLs. Mercury concentrations detected in the (unfiltered) sample from MW-21 and the (filtered) sample from artesian well FW-3 slightly exceed the WQS. Several of the groundwater mercury results were rejected due to poor matrix spike recovery (see Section 4.5.1).

4.3.3 Comparison of First- and Second-Round Data

TPH Results. TPH-kerosene was detected only in the second sampling round. The lack of TPH-kerosene detections in the first round may be due to the lower MRL achieved for the second round (a different analytical laboratory was used for the second round). The distributions of TPH-gasoline and TPH-kerosene correspond with the BTEX plume area. The lack of correlation between first- and second-round TPH results may indicate a problem with the first round laboratory's TPH analyses. The second-round TPH results correlate well with the BTEX results; therefore, the second-round TPH results are likely to represent actual field conditions.

VOC Results. All VOC concentrations detected in both the first and second groundwater sampling rounds are below WQSs and DOH Tier 1 action levels. BTEX concentrations detected at MW-2 and MW-15 declined slightly over the approximately 1-year period between the two sampling rounds for the Phase II RI. However, BTEX concentrations detected at these two wells in 1998 and 1999 are much lower than those detected during the last round of Phase I RI groundwater sampling in 1994. The core of the BTEX plume has not shifted downgradient since 1994, and the plume is remaining well within the site boundary.

SVOC Results. All SVOC concentrations detected in both the first and second groundwater sampling rounds are below WQs and DOH Tier 1 action levels.

Metal Results. Lead concentrations detected in samples from both the onsite and offsite monitoring wells are very low. Lead levels above 1 µg/L were detected in only three monitoring wells. All monitoring well lead detections are below 1.5 µg/L. The elevated lead levels detected in turbid groundwater samples from the offsite microwells appear to be related to the high suspended solids content of these samples, not to the 1971 MOGAS release. (None of the monitoring well or microwell groundwater samples were filtered.) The other metals detected in the caprock water-bearing zone also appear to be unrelated to the MOGAS release.

4.4 QUALITY CONTROL SAMPLES

The field QC samples consist of field blanks, field duplicates, trip blanks, equipment rinsates, and PE samples. As discussed in Section 2.7, field QC samples are collected to help monitor sampling procedures and identify potential outside sources of contamination.

4.4.1 Field QC Samples

Seventeen field duplicate pairs were collected and analyzed. In accordance with U.S. Navy PACDIV IRP Level D QC requirements (DON 1996, 1998), the field duplicates represent approximately 10 percent of the total number of samples analyzed. Trip blanks, field blanks, and equipment rinsate samples were also collected and analyzed in accordance with U.S. Navy PACDIV IRP Level D QC requirements. Field QC samples are listed in Table 4-7; field QC sampling results are detailed in Appendix I.

Table 4-7: QC Samples Collected and Analyzed

QC Sample Type	Analytical Method				
	EPA 8015B	EPA 8260B	EPA 8270C SIM	CLP ILM04.0	EPARSKOP-175 Modified ^a
Field blank	7	4	7	7	3
Field duplicate	13	14	11	13	8
Trip blank	54 ^b	48	NA	NA	NA
Equipment rinsate	22	22	22	22	12

NA = not analyzed

^a Sample preparation and determination of dissolved gases in water using gas chromatography headspace equilibration technique (Kampbell, Wilson, and Vandergrift 1989)

^b Trip blanks analyzed for TPH-gasoline only.

4.4.2 Performance Evaluation Samples

An independent vendor prepared and supplied a PE sample for each phase of the project. The results of the PE sample analyses are intended to help evaluate the accuracy of the fixed-base analytical laboratory performance for analytical methods CLP OLM03.0, EPA 8260B, EPA 8270C SIM, CLP ILM04.0 EPA 8015B and selected general chemistry parameters. Performance acceptance limit (PAL) guidelines for each analytical method, supplied by the vendor, were used to evaluate the reported concentrations of analytes from the methods presented in Table 4-8. Laboratory-reported concentrations for detected compounds outside the listed PALs may indicate over- or underestimation of sample concentrations.

During round-one sampling, one double-blind soil PE sample (VA069) and one double-blind water PE sample (VA586) were prepared and submitted for analysis. During round-two sampling, one single-blind water PE sample (VA730) was prepared and submitted for analysis.

The PE sample analytical methods are listed in Table 4-8; results of the PE sample analyses are discussed in Section 4.5.1.

With the exception of the BEHP concentration in the first-round water PE sample, the overall analytical laboratory performance for all PE sample analyses are considered acceptable.

Table 4-8: Summary of PE Sample Analytical Methods

PE Sample Type	Analytical Method								
	CLP VOCs	CLP SVOCs	EPA 8015B	EPA 8260B	EPA 8270C	ILM04.0	[Methane] EPA RSKOP-175 Modified	[Fluoride] EPA 340.2	[Chloride] EPA 300
Soil	x	x							
Aqueous									
Round One	x	x	x			x	x		
Round Two				x	x	x		x	x

4.4.2.1 SOIL PE SAMPLE

During the first round of sampling, the analytical laboratory demonstrated performance within PAL acceptance criteria for all compounds except the five listed in Table 4-9. It should be noted that all initial calibration, continuing calibration, surrogates, and internal standards were within QC acceptance criteria for these compounds. Therefore, the PAL exceedances for the compounds listed above are considered sample-specific and are not indicative of incorrect analytical procedures.

Table 4-9: PAL Exceedances in PE Samples

Compound	Reported Analytical Result	Exceedance of PAL
First-Round Soil PE Sample		
Benzene	10.5 µg/kg	Below lower acceptance limit of 11.3 µg/kg
Carbon tetrachloride	18.5 µg/kg	Below lower acceptance limit of 26.9 µg/kg
4-Chloro-3-methylphenol	1,650U µg/kg (non-detected)	Outside acceptance limits of 2,030–6,930 µg/kg
Pentachlorophenol	1,221 µg/kg	Below lower acceptance limit of 1,240 µg/kg
Toluene	25.2 µg/kg	Above upper acceptance limit of 23.5 µg/kg
First-Round Water PE Sample		
Benzo(b)fluoranthene	10.0U µg/L (non-detected)	Outside acceptance limits of 7.71–23.3 µg/L
BEHP	1,318 µg/L	Above upper acceptance limit of 142 µg/L
Butylbenzylphthalate	49.2 µg/L	Above upper acceptance limit of 44.9 µg/L
Chrysene	6.34 µg/L	Below lower acceptance limit of 10.6 µg/L
Di-n-octylphthalate	48.96 µg/L	Below lower acceptance limit of 54.6 µg/L
Hexachlorobenzene	18.59 µg/L	Below lower acceptance limit of 19.4 µg/L

Compound	Reported Analytical Result	Exceedance of PAL
Second-Round Water PE Sample		
Arsenic	60 µg/L	Below lower acceptance limit of 87.8 µg/L
Hexachlorobenzene ^a	50 µg/L	Below lower acceptance limit of 50.8 µg/L
Pyrene ^a	49 µg/L	Below lower acceptance limit of 52.4 µg/L

^a In the second-round analyses, both hexachlorobenzene and pyrene were reported within acceptance limits in a diluted sample. However, these results were not used, as the original results were within the standard calibration range.

4.4.2.2 WATER PE SAMPLES

Round One. During the first round of groundwater sampling, the analytical laboratory demonstrated performance within the PALs for all compounds except the six listed in Table 4-9. It should be noted that the PE sample, along with the rest of the samples in the extraction batch, was diluted due to a high concentration of BEHP. The data validation report states that the high concentrations of BEHP are laboratory-derived and not indicative of actual site conditions. The validation report further states that the low PE sample recoveries may be attributable to the BEHP contamination, which is an interference with chrysene-d12, the internal standard used to quantitate many of these compounds.

Round Two. For the second round of groundwater sampling, the fixed-base analytical laboratory demonstrated performances within PAL acceptance criteria for all compounds except for the three listed in Table 4-9. For arsenic, it should be noted that all calibration criteria, interference check sample analyses, and laboratory control sample (LCS) analyses were within QC acceptance criteria; therefore, the PAL exceedance for arsenic is considered sample-specific and not indicative of incorrect analytical procedures.

4.5 DATA VALIDATION

The analytical data were subjected to independent third-party data validation to provide assurance that the data are adequate for the intent of this project. All data were validated by an independent subcontractor according to the U.S. Navy PACDIV IRP *Project Procedures Manual* (DON 1996, 1998) and *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics and Organics Analysis* (EPA 1994b,c). Data qualifiers were applied in cases where the data do not meet the required QC criteria, or where special consideration by the data user was required. Definitions of standard data qualifiers are presented in Table 4-10.

Table 4-10: Qualifier Definitions

Qualifier	Description of Data Qualifier Reference Code
U	Indicates the compound or analyte was analyzed for but not detected at or above the stated limit.
J	Indicates an estimated value.
R	Quality control indicates the data are not usable.
N	Presumptive evidence of presence of the constituent.
NJ	Presumptive evidence of presence of the constituent at an estimated value.
UJ	Indicates the compound or analyte was analyzed for but not detected. The sample detection limit is an estimated value.

Qualification codes were also applied to the data to explain why the various data qualifiers were applied. A complete qualification code table is found DON (1996, 1998), Procedure II-A, *Data Validation Presentation*, Attachment II-A-5.

Individual data validation reports were produced for sample delivery groups. The data validation reports are compiled in Appendix K.

4.5.1 PARCC Report Summary

A detailed summary report of all data validation reports was also produced. This report, which evaluates precision, accuracy, representativeness, comparability, and completeness (PARCC) parameters for all analytical data, is presented in Appendix L.

A summary of overall PARCC parameters indicates that the data meet the Phase I and Phase II RI data quality objective (DQO) goals. Therefore, the data are useable for their intended purpose.

Precision. The overall precision for soil and water analyses achieved by the analytical laboratory is 95.2 percent, achieving the project DQO goal of 90 percent. Of the 1,105 total QC analyses, 57 exceed the relative percent difference (RPD) criteria. The reported precision for volatiles and metals in the first phase is below the 90 percent DQO goal, at 87.5 percent and 79.4 percent, respectively. For volatiles, the low percentage during the first round of sampling is attributable to three soil matrix spike/matrix spike duplicate (MS/MSD) pairs with percent recoveries and RPDs outside the QC criteria. The validation reports indicate that these QC exceedances may be attributable to matrix heterogeneity and that no quantifiable bias is evident. The low metals precision percentage is due to many duplicate RPDs exceeding the QC criteria. The validation reports attribute the QC exceedances to matrix effects, since all RPDs for the LCS/LCS duplicates are acceptable.

Accuracy. The overall accuracy is 96.3 percent, achieving the corresponding project DQO accuracy goal of 90 percent. Of the 3,932 total recoveries, 146 exceed QC limits. The reported accuracy for metals and wet chemistry in the first phase is below the 90 percent goal, at 66.7 percent and 77.7 percent, respectively. The data validation reports indicate these low accuracy percentages are attributable to sample matrix interference, since percent recoveries for the LCS/LCS duplicates were acceptable.

Representativeness. The representativeness parameter is considered acceptable in the PARCC report, because all samples were evaluated for holding time compliance and associated with a method blank in each individual SDG. It should be noted that seven samples, including the performance evaluation sample, had concentrations of BEHP that are not considered representative of the site. The PARCC report states that data reviewed during the PACDIV Level D validation indicate the source of the phthalate is most likely the laboratory and not the groundwater at the site.

Comparability. The comparability parameter is considered acceptable, since sample frequency requirements were met in obtaining duplicates and necessary field blanks, standard analytical methods were used, and data were reported in correct standard units.

Completeness. The overall completeness is 99.4 percent, achieving the project DQO completeness goal of 90 percent. Of the 20,046 total reported analytes, 121 were rejected due to high RPDs or exceedance of sample holding times. Ninety-six semivolatile analyses in five samples were rejected due to poor surrogate or internal standard recovery. Nine mercury results in nine samples were rejected due to poor MS recovery. Sixteen PAH results in one sample were rejected due to poor surrogate recovery.

4.6 SUMMARY OF NATURE AND EXTENT

Phase II RI analytical results are compared to risk-based screening criteria in Table 4-11.

Table 4-11: Summary of Phase II RI Analytical Results

Contaminant Type	Caprock Groundwater	Basal Groundwater	Subsurface Soil	Surface Soil	Sediment	Surface Water
Potentially MOGAS-Related						
BTEX	Below screening criteria	ND	Below screening criteria	ND	ND	ND
1,2-Dichloroethane	Below screening criteria	ND	Below screening criteria	ND	ND	ND
Light-end SVOCs	Below screening criteria	ND	Below screening criteria	ND	ND	Below screening criteria
Lead	Below screening criteria	ND	Below screening criteria	Detected but not MOGAS-related	Detected but not MOGAS-related	Detected but not MOGAS-related
Not MOGAS Related						
VOCs (laboratory contaminants)	Below screening criteria	ND	Below screening criteria	ND	Below screening criteria	Below screening criteria
Heavy-end SVOCs (including phthalates)	Below screening criteria	ND	Below screening criteria	Below screening criteria	Above screening criteria	Above screening criteria
Metals (including lead not MOGAS-related)	Above screening criteria	Below screening criteria	Below screening criteria	Below screening criteria	Above screening criteria	Above screening criteria

ND = not detected

Based on the nature and extent of contamination described above, the following conclusions have been reached regarding contamination observed during the Phase II RI:

- Offsite surface soil, surface water, and sediment do not appear to contain petroleum hydrocarbons related to the 1971 MOGAS release. MOGAS constituents such as TPH, BTEX, and 1,2-DCA were not detected in any of these samples. Other VOCs, such as acetone, 2-butanone, and carbon disulfide (common laboratory reagents), were detected at low levels in samples from throughout the investigation area and are not expected to be related to the MOGAS release.
- Hydrocarbons associated with the 1971 MOGAS release do not appear to have reached offsite subsurface soil or groundwater at significant concentrations. Very low levels (well below screening criteria) of contaminants associated with MOGAS (such as BTEX, 1,2-DCA, and low-molecular-weight [LMW] SVOCs and PAHs) were detected in subsurface soil and groundwater samples collected along Waiawa Road just south of the site boundary.
- HMW PAHs (C16–C22 range hydrocarbons) were detected at low concentrations in surface samples (surface soil, surface water, and sediment) from throughout the offsite area. These HMW PAHs, which are typically associated with heavier fuels and internal combustion engine emissions, are not related to the MOGAS released at the EJFDF (see Appendix J for product information). LMW SVOCs and PAHs, which are commonly associated with MOGAS, generally were not detected in the offsite surface samples. The offsite areas on both sides of the unnamed stream (i.e., the offsite investigation area and the area east of the unnamed stream) contain many potential sources of hydrocarbon contamination, including

fuel pipelines, fill storage piles, abandoned vehicles (e.g., buses), and areas where heavy equipment is operated, maintained, and stored (see Figure 3-1 and Figure 3-3).

In addition, a 1987 pipeline leak released 120,000 gallons of "Jet A" fuel into the wetland complex beside the bicycle path north of the Pearl City Peninsula Landfill, and south of the Nakatani Farm (Ogden 1995). Several thousand gallons of jet fuel were accidentally pumped into the Waiawa Wildlife Refuge ponds. Much of the remaining spilled fuel flowed into Middle Loch via the unnamed stream.

The Navy's ongoing Pearl Harbor Sediment Study (Ogden, in progress) notes that HMW PAHs were detected in Middle Loch sediments, at sampling location 4ez approximately 300 feet west of the mouth of the unnamed stream (540 µg/kg), and at location 4ax approximately 1,000 feet south of the mouth of the unnamed stream (1,781 µg/kg). HMW PAH concentrations in both of these samples exceed the screening value for total HMW PAHs. LMW PAHs were detected in the sediment at location 4ax at 272 µg/kg, and at 4ez at 138 µg/kg. These concentrations do not exceed marine sediment screening values. The lowest concentrations of both LMW and HMW PAHs were detected along the shore at sampling location 4ez. The highest concentrations were detected offshore in Middle Loch at location 4ax. Lead was detected at locations 4ax and 4ez at 40.7 and 12.88 mg/kg, respectively. Both detections are below the marine sediment screening value (ER-L) of 46.7 mg/kg. The highest concentrations of PAHs in the Middle Loch sediment samples represent HMW PAHs with three or more rings. The source of these HMW PAHs is more likely to be the spilled jet fuel from the pipeline than the MOGAS spill from EJFDF. The low levels of lead detected in the harbor sediment samples provide further evidence that the PAH contamination is not associated with the (leaded) MOGAS.

- Low levels of BEHP were detected at surface sampling locations distributed throughout the offsite study area. Relatively high concentrations of BEHP were detected in sediment and surface water samples collected near a storm sewer outfall to the harbor. The BEHP detections are not likely to be related to the MOGAS release. BEHP is a common laboratory contaminant, and is often detected in urban stormwater runoff (due to its presence in plastics, a ubiquitous stormwater waste product [Lyman et al. 1982].)
- Results of the EJFDF Phase I and Phase II RIs show that the lead detected in investigation area soil and groundwater is not likely to be associated with the MOGAS release. Phase I RI soil sampling results showed little or no correlation between total fuel hydrocarbon (TFH) concentrations and total lead concentrations. For example, the Phase I RI soil sample with the highest total lead concentration contained no detectable TFH. The spatial distribution of lead in both soil and groundwater also indicates that lead potentially associated with the MOGAS release has not significantly impacted the investigation area: lead concentrations detected in soil samples from the offsite area, hundreds of feet downgradient of the MOGAS source (UST S-26), were higher than they were in the onsite area immediately downgradient of the source. Lead was detected in offsite (Phase II RI) surface soil samples at higher concentrations than in any of the (Phase I RI) onsite surface or subsurface soil samples. In the offsite area, lead was detected at maximum concentrations of 45 mg/kg in surface soil, and 56.1 mg/kg in sediment, whereas the maximum onsite surface soil lead concentration was only 18.5 mg/kg. Onsite subsurface soil lead concentrations were even lower—the maximum concentration was 7.8 mg/kg. The maximum lead concentration detected in offsite subsurface soil was only 3 mg/kg.

These results strongly suggest that the lead is associated with a surface source, whereas contaminants associated with the MOGAS release would migrate through the subsurface, either as free-product floating on the water table, or with groundwater in the dissolved phase. The maximum total lead concentration detected in the (unfiltered) groundwater samples

collected onsite in the MOGAS source zone and immediately downgradient of the source zone during the Phase II RI was only 1.455 µg/L, whereas lead concentrations detected in the offsite groundwater were up to 189 µg/L. The low lead levels in the MOGAS source area groundwater relative to the offsite groundwater indicate that the lead is not likely to be associated with the MOGAS release. The lead detected in the Phase II RI offsite groundwater samples was most likely associated with suspended soil particles. Elevated lead levels in surface water samples from the watercress patches also appear to be related to suspended solids in the unfiltered samples, not the MOGAS release.

- Data collected during the Phase I RI indicates that the lead detected in EJFDF investigation area soil and groundwater is in the inorganic form. Soil and groundwater samples collected during the Phase I RI were analyzed for both organic and total lead. Organic lead was not detected in surface or subsurface soil samples collected from onsite trenches and borings downgradient of UST S-26. Total lead levels detected in the soil samples ranged from 2.1 to 18.5 mg/kg. In addition, although up to 325 µg/L of total lead was detected in an (unfiltered) Phase I RI groundwater sample, organic lead was not detected in any of the Phase I RI groundwater samples.
- It is extremely unlikely that either the unnamed stream that flows along the eastern margin of the offsite investigation area or the Waiawa Unit of the Pearl Harbor National Wildlife Refuge is impacted by the EJFDF MOGAS release. The groundwater contaminant plume associated with the MOGAS release extends toward the south and southwest, and is essentially confined within the EJFDF site boundaries. The plume geometry is strong evidence that the hydrogeological characteristics of the investigation area cause groundwater from the onsite area to flow toward the south and southwest—not southeast toward the unnamed stream and the Waiawa Unit. Furthermore, as noted in Section 3.1.3, water for the Waiawa Unit is not drawn from the unnamed stream. The water source for the refuge is the freshwater marsh east of Nakatani Farm. The freshwater marsh is not downgradient of the EJFDF and is more than 1,500 feet away from the southeast corner of the site; therefore, groundwater from the site cannot impact the water source for the wildlife refuge.

5. CONTAMINANT FATE AND TRANSPORT

Results of the Phase II RI and previous EJFDF investigations are interpreted to evaluate contaminant fate and transport in the Phase II RI investigation area. The evaluation is based on the physical characteristics of the investigation area, potential contaminant sources, and the nature and extent of contamination.

Phase II RI analytical results indicate that contaminants associated with the EJFDF MOGAS release have remained almost completely within the site boundary, in subsurface soils and caprock groundwater near the MOGAS source. Phase II RI findings provide strong evidence that natural attenuation has greatly decreased caprock groundwater contaminant concentrations over the 28 years since the MOGAS release, and that this attenuation reduces concentrations to very low levels well before the groundwater reaches the downgradient site boundary. Contaminants detected in offsite surface soil, sediments, and surface water are not likely to be associated with the MOGAS release.

5.1 CONTAMINANT TRANSPORT PATHWAY COMPONENTS

A contaminant transport pathway is the course a chemical takes from a source to a biological receptor. A contaminant transport pathway is considered complete if all four of the following pathway elements exist:

- Contaminant source
- Transport media
- Exposure point
- Exposure route

Figure 5-1 illustrates potentially complete contaminant transport pathways for contaminants from the 1971 UST MOGAS release. Exposure pathways are discussed below.

The original or primary contaminant source at the EJFDF was the UST S-26 MOGAS release; however, the only significant contaminant source remaining at the site appears to be residual soil contamination in the vicinity of UST S-26 (Ogden 1996).

A transport medium carries contamination to the exposure point. Air may carry gas-phase contaminants or wind-blown particulates. As discussed in the Phase I RI Report (Ogden 1996), air, soil, surface water, and groundwater are potential contaminant transport media at the EJFDF. However, most of the residual soil contamination is in the subsurface; therefore, groundwater transport is the principle transport mechanism of concern.

An exposure point is a location where biological receptors may directly contact contaminants. Potential exposure points in the EJFDF investigation area include potentially contaminated onsite surface soil and air, as well as offsite surface water and air potentially impacted by EJFDF caprock groundwater. The Phase I RI discussed the potential threats from onsite exposures; therefore, the focus of this study is on impacts to receptors at offsite exposure points. Pearl Harbor represents the principle offsite exposure point. Hydrogeologic evidence and analytical data indicate that the caprock water-bearing zone discharges directly to Pearl Harbor, not to the offsite agricultural area.

After a chemical reaches an exposure point, it may enter the system of a biological receptor by an exposure route, e.g., ingestion, inhalation, dermal contact. Potential exposure routes and associated risks are discussed further in Sections 5.4, 6, and 7.

5.2 INDICATOR CHEMICALS

Chemicals of potential concern (COPCs) detected in the EJFDF investigation area were screened to identify ICs. The overall fate and transport of a class of COPCs can be evaluated by focusing on the fate and transport of ICs. Individual chemicals with toxicological, fate, and transport properties that conservatively represent a class of COPCs can serve as ICs.

5.2.1 Identification of COPC Classes

VOCs and lead were identified as COPCs for the EJFDF: these chemicals are common MOGAS constituents and have been detected at concentrations above ARAR or TBC criteria (e.g., Hawaii DOH Tier 1 action levels) in EJFDF groundwater or soil. SVOCs associated with MOGAS (such as methylnaphthalene and phenolic compounds) were not selected, since they were not detected above their respective screening criteria (see discussion in Section 4). Other heavier SVOCs (greater than C16 range hydrocarbons), which are not common constituents of MOGAS and were not detected at significant concentrations on site, are likely not associated with the 1971 MOGAS release. These compounds were not considered as ICs for the EJFDF.

5.2.2 Selection of Indicator Chemicals

ICs for the Phase II RI fate and transport evaluation were selected on the basis of the following criteria:

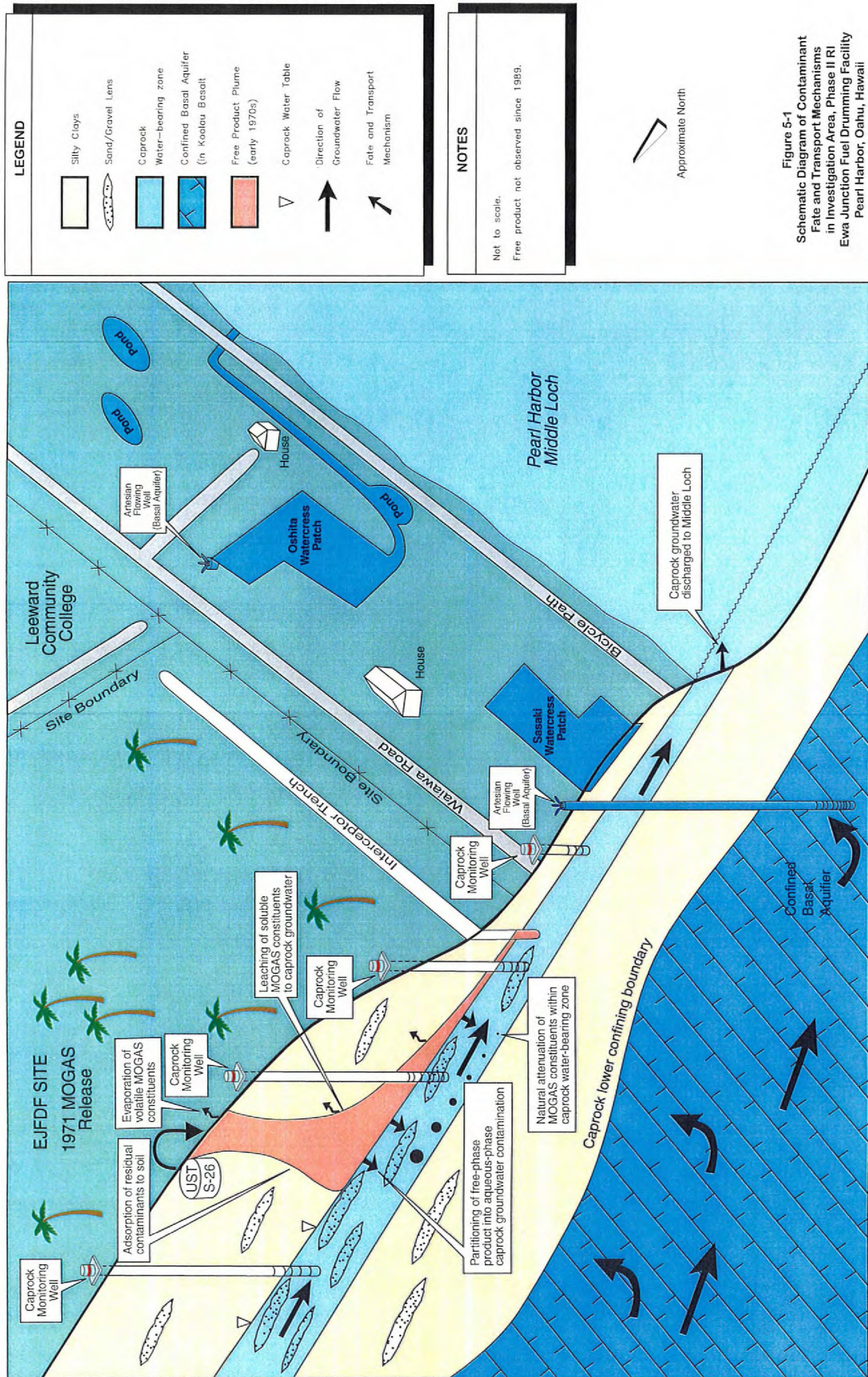
- The physicochemical properties of the chemicals indicate a potential to either persist or migrate to an exposure point.
- The chemicals have been detected at levels that may threaten human health or the environment.

The following chemicals were selected as ICs:

- BTEX compounds
- 1,2-DCA
- Lead

The BTEX compounds represent the most mobile and toxic MOGAS constituents. BTEX has been consistently detected at elevated concentrations in groundwater samples collected on site, downgradient of the MOGAS source area, during the Phase II RI and previous investigations. Another VOC compound, 1,2-DCA, is present in onsite caprock groundwater and is associated with gasoline products.

Lead, a common gasoline constituent, was selected as an IC due to its toxicity, persistence in the environment, ability to migrate in groundwater and surface water in either the aqueous phase, or on suspended particulates. In addition, elevated lead concentrations were detected in surface water and sediment samples collected in the offsite area during the Phase II RI.



5.2.3 Properties of Indicator Chemicals

Physicochemical properties of the ICs, and the human health and ecological effects of these chemicals are summarized here; more detailed information is presented in the Phase I RI report (Ogden 1996).

Benzene. Benzene is a light, single-ring, aromatic gasoline component. Due to its relatively high solubility and low tendency to adsorb to organic carbon, it is very mobile in the aqueous phase compared to other gasoline components. Benzene is moderately to highly volatile, thus it will readily evaporate upon exposure to the atmosphere. Benzene that reaches the atmosphere is expected to be oxidized by hydroxyl radicals (Ogden 1996). Benzene has been shown to biodegrade in groundwater under both aerobic and anaerobic conditions (Weidemeier et al. 1995).

Benzene is readily absorbed through ingestion, moderately absorbed through inhalation, and poorly absorbed through dermal contact. Large doses of benzene have produced central nervous system depression, headache, dizziness, nausea, convulsions, coma, and death. Chronic benzene exposure causes irritation at the site of contact, and affects the liver and other organs. The EPA has identified benzene as a Group A human carcinogen by inhalation. Benzene is also assumed to be carcinogenic via ingestion, and has been shown to be mutagenic. Although benzene does not bioaccumulate rapidly, it can bioaccumulate to moderately high concentrations.

Toluene. Toluene, also a single-ring, aromatic gasoline component, is relatively hydrophilic and moderately soluble in water. This compound is relatively mobile in the aqueous phase. Toluene's volatility, combined with its moderate tendency to sorb to organic carbon, indicates that evaporation may remove significant quantities of toluene from surface soil and sediments. Toluene is also expected to volatilize relatively quickly from surface water. The half-life (the time required to reduce the concentration by 50 percent) of toluene in the atmosphere has been estimated at approximately 15 hours (Callahan et al. 1979). Toluene has been shown to biodegrade in groundwater under both aerobic and anaerobic conditions (Weidemeier et al. 1995).

Toluene is well absorbed orally and by inhalation. Acute exposure causes irritation (including chemical pneumonia if liquid is aspirated into the lungs) and central nervous system depression, even at concentrations as low as 100–200 parts per million in air. Extremely high concentrations are reportedly toxic to the liver and kidneys, and may reversibly decrease erythrocyte levels. Although quantitative human data are not available, chronic exposure affects the skin (dissolving secreted fat), central nervous system, liver, and kidneys. Toluene was not found to be mutagenic in the few reported studies, and available studies have not demonstrated carcinogenicity or reproductive toxicity.

Ethylbenzene. Ethylbenzene, another single-ring, aromatic gasoline component, is also relatively mobile in the aqueous phase. Ethylbenzene is moderately soluble and slightly less hydrophilic than the other BTEX compounds. Although ethylbenzene sorbs to organic carbon to a greater extent than the other BTEX compounds, sorption and retardation will not prevent migration in most soils. The physicochemical properties of ethylbenzene indicate a relatively strong tendency to partition to the atmosphere (Mackay 1979). Ethylbenzene has also been shown to biodegrade in groundwater under both aerobic and anaerobic conditions (Weidemeier et al. 1995).

Ethylbenzene is well absorbed from the lungs and gastrointestinal tract, but poorly absorbed through the skin. Small amounts are exhaled unchanged, but most is metabolized in the liver. Acute doses of ethylbenzene are highly irritating, especially to sensitive tissues, such as the eyes and lungs. Repeated inhalation may lead to inflammation of the respiratory tract. Large doses produce central

nervous system depression. Chronic exposure reportedly causes a number of lung, nervous system, bone marrow, and hepatic lesions. Mild, nonspecific adverse effects, such as retarded skeletal development, were observed in the few available animal reproductive studies. Carcinogenicity studies are not available for ethylbenzene.

Xylenes. The xylene isomers ortho-, meta-, and para-xylene are also single-ring, aromatic gasoline components. Xylenes are moderately soluble in water, have a moderate tendency to adsorb to organic carbon, and are relatively mobile in the aqueous phase. The potential for volatilization of xylene from surface soil and water is expected to be similar to that of toluene. Xylene reportedly breaks down in the atmosphere at a rate of 67–86 percent per day (National Library of Medicine 1987).

Xylene is rapidly absorbed through the lung and gastrointestinal tract, and slowly absorbed through the skin. Most absorbed xylene is oxidized in the liver and excreted in the urine. Experimental results indicate minimal potential for bioaccumulation of xylenes (Ogata and Miyake 1978). The toxicity of xylene is similar to that of toluene. Acute doses produce central nervous system depression and irritation at the contact site. Repeated doses cause lesions at the contact site, a variety of central nervous system effects, and some liver lesions. No specific effects have been observed in reproductive toxicity studies, and there is no evidence of carcinogenicity in the few animal studies available.

1,2-DCA. 1,2-DCA is a relatively lightweight chlorinated VOC, commonly used as a gasoline additive to remove lead. 1,2-DCA is highly soluble in water and has a low affinity for organic carbon; therefore, it is relatively mobile in the aqueous phase. 1,2-DCA released to the land surface is expected to volatilize rapidly to the atmosphere; however, once 1,2-DCA has infiltrated through the upper layer of soils, volatilization occurs more slowly. 1,2-DCA is heavier than water (specific gravity is 1.25 at 20°C); therefore, it tends to sink below the water table in the pure phase. In the presence of sufficient excess volumes, it tends to overcome soil retention factors, such as capillary effects. Transport characteristics of dissolved phase 1,2-DCA are similar to those of other dissolved contaminant compounds of lesser density. Microorganisms are capable of degrading 1,2-DCA in groundwater (ATSDR 1992). The presence of methane, or an increase in the proportion of methanotrophs, can accelerate the rate of aerobic biodegradation of 1,2-DCA in soil (Speitel and Closmann 1991).

1,2-DCA does not tend to bioaccumulate in animals or plants, but can be absorbed orally, dermally and by inhalation. 1,2-DCA is metabolized in the liver. Acute doses cause irritation at the site of contact and central nervous system depression. Large or repeated doses also produce lesions in the liver, kidney, and adrenals. The few reproductive studies reported no adverse effects. Carcinogenesis studies in rats and mice found that 1,2-DCA produced a variety of tumors. 1,2-DCA has been assigned a weight-of-evidence of B₂, a probable human carcinogen (EPA 1995) (see Section 6.1.2.3).

Lead. The MOGAS released at the EJFDF is believed to have contained tetraethyl lead, which has been used as an antiknock additive in gasoline. The Ethyl Corporation and the Navy's Environmental and Preventive Medicine Unit No. 6, which were consulted shortly after the release in 1971, indicated that tetraethyl lead is not soluble in water and will evaporate along with the VOC components of MOGAS (Mau 1972). However, tetraethyl lead may be converted to inorganic lead compounds relatively quickly (HLA 1990). Lead and lead compounds show a wide range of solubility and are highly persistent in water, with a half-life of over 200 days (EPA 1985).

Lead has been detected in offsite soil, surface water, sediments, and groundwater. However, the MOGAS release is not likely to be a source of the lead detected off site. The maximum lead concentration detected in unfiltered caprock groundwater samples collected from the offsite microwells was 189 $\mu\text{g/L}$. However, the maximum lead concentration detected among the onsite monitoring well samples was only 1.18 $\mu\text{g/L}$, and lead was not detected in the offsite monitoring wells. The turbidity of the microwell groundwater samples was very high compared with the monitoring well samples. This suggests that the lead detected in the microwell samples (and the surface water samples) is most likely associated with suspended soil particles.

Experimental data suggest that, among human populations, the fetus and young child, particularly under 3 years of age, are at increased risk of adverse effects (NRC Safe Drinking Water Committee 1977). In adults, exposure to lead can damage the peripheral nervous system, affecting memory, vision, and muscle coordination, and causing weakness in the fingers, wrists, or ankles. Absorption at high levels can damage kidneys, result in anemia and miscarriage, and decrease fertility in both men and women. The effects of chronic low-level lead exposure on adult health are not clear, but chronic exposure may be associated with hypertension and heart disease (EPA 1985). Lead can also produce detrimental effects on ecosystems, including low growth rates in plants; developmental, reproductive and nervous system problems in mammals, birds, and fish; and, in severe cases, death (EPA 1985).

5.3 CONTAMINANT TRANSPORT MEDIA

Contaminant transport media allow contaminants to migrate from their sources to areas or points where biological receptors may directly contact the chemicals (exposure points). As discussed in the Phase I RI, air, soil, surface water, and groundwater are potential contaminant transport media at the EJFDF (Ogden 1996). However, onsite surface soils contain very low levels of MOGAS-related contaminants; therefore, surface soil contact and transport via air are not considered significant pathways. The main transport mechanisms discussed below are subsurface soil leaching and groundwater transport. Surface water transport is also discussed because the caprock groundwater discharges to Pearl Harbor waters.

5.3.1 Soil

Contaminants may migrate through the soil in the liquid, gas, or solid phase (e.g., as suspended particulates). Liquid-phase migration includes transport of contaminants in the dissolved (i.e., aqueous phase), and as free-phase liquids. Contaminants may migrate directly to an exposure point, or they may migrate downward to groundwater.

The physical and chemical properties of soil affect contaminant transport. Physical characteristics such as hydraulic conductivity influence contaminant migration in the liquid phase. Transport of organic contaminants may be retarded by reversible sorption to organic carbon particles in the soil. Retardation is most pronounced when soil contains a high percentage of organic carbon and the contaminants have a high affinity for organic carbon. Because the hydraulic conductivity of EJFDF soils is relatively low, aqueous-phase MOGAS constituents migrate relatively slowly (Ogden 1996). Reversible sorption to organic carbon particles in EJFDF soil also acts to decrease contaminant transport velocities within the caprock water-bearing zone (see discussion in Section 5.4.3.1).

Results of the Phase II RI and previous investigations indicate that residual MOGAS constituents are slowly leaching from EJFDF subsurface soils and migrating downward to the caprock water-bearing zone. Free product has not been observed at the EJFDF since the HLA (1989) investigation; therefore, partitioning of free product into the aqueous phase is no longer a significant transport

pathway. Residual MOGAS constituents in subsurface soil appear to represent the only significant source of contamination remaining at the site. Leaching is most pronounced during periods of heavy rainfall. Temporary increases in the elevation of the water table may also increase the rate of hydrocarbon dissolution by increasing the volume of contaminated soil in contact with groundwater.

The highest TPH and VOC concentrations found in EJFDF soil were detected in a soil sample collected at 30 feet bgs, from a boring (B-1) advanced on the southeast side of UST S-26 in 1989 (ESE 1990). TPH-gasoline was detected in this sample at 21,900 mg/kg, toluene at 78 mg/kg, xylene at 1,700 mg/kg, and ethylbenzene at 190 mg/kg. Although low-solubility hydrocarbons may persist in subsurface soil for long periods, Phase I RI sampling results indicate that concentrations of the BTEX compounds and other soluble MOGAS constituents are decreasing. For example, a soil sample collected less than 2 feet above the water table from a boring advanced downgradient of UST S-26 during the Phase I RI showed a TPH concentration of 510 mg/kg, but no VOCs were detected. Mechanisms likely to contribute to the reduction in concentrations of VOC in subsurface soil include leaching, evaporation, and biodegradation.

5.3.2 Groundwater

Gasoline is lighter than water; therefore, it can float on the water table and migrate downgradient as LNAPL. Gasoline constituents may also be transported as dissolved (aqueous-phase) contaminants. LNAPL has not been detected in onsite wells since 1989; however, aqueous-phase MOGAS constituents have continued to migrate in caprock groundwater at the EJFDF.

Porosity, hydraulic conductivity, and hydraulic gradient affect seepage velocity; these characteristics play a major role in aqueous-phase contaminant transport. As discussed above, organic contaminants are retarded by reversible sorption to organic carbon. Therefore, the percentage of organic carbon in the aquifer matrix and the contaminant's affinity for organic carbon may greatly affect groundwater contaminant transport.

The primary concern associated with migration of contaminated caprock groundwater from the EJFDF is the potential impact of aqueous-phase MOGAS constituents on the downgradient agricultural/wetlands area and Pearl Harbor. The caprock groundwater is not used for human consumption in the EJFDF area. In addition, the caprock groundwater is not considered a viable source of potable water in this area due to the relatively low hydraulic conductivity within the water-bearing zone, and relatively high concentrations of TDS (approximately 1,000–3,000 mg/L [Ogden 1996]). Contaminants in caprock groundwater are also not expected to threaten the confined basal aquifer, the main drinking water supply for Oahu, since the hydraulic head for the caprock water-bearing zone is lower than that for the confined basal aquifer, as described in Section 3.8.2. Dissolved contaminants in caprock groundwater could migrate laterally and discharge to surface waters in Pearl Harbor Middle Loch.

In the past, MOGAS constituents at the EJFDF have been transported as LNAPLs floating on the caprock water table; however, nonaqueous phase migration is no longer occurring. Most of the floating LNAPL was removed by remedial efforts in the early 1970s. The flux of soluble gasoline constituents into the aqueous phase was probably relatively high during the first years after the gasoline release, when large quantities of LNAPL were floating on the water table. Free product has not been observed since early 1989; therefore, residual gasoline constituents suspended between soil particles or sorbed to the soil just above the water table are the only significant sources of contamination remaining at the site. Although soluble hydrocarbons may continue to slowly leach from low-permeability silty vadose zone soils into the caprock groundwater, leaching is unlikely to impact groundwater nearly as much as direct contact with large quantities of free product.

Therefore, the flux of contaminants into the aqueous phase would have been greatly reduced after the free product was eliminated. In addition, results of the natural attenuation evaluation presented below suggest that electron acceptor concentrations in the caprock groundwater are high enough to degrade soluble hydrocarbons faster than they are leached from source area soil. (Microorganisms utilize electron acceptors, such as dissolved oxygen and nitrate, to oxidize organic compounds.) The decrease in EJFDF caprock groundwater BTEX and 1,2-DCA concentrations observed over time supports this conclusion.

The reduction in BTEX and 1,2-DCA concentrations with both time and with distance downgradient of the source area, coupled with the distribution and concentration of electron acceptors relative to the BTEX plume, provides strong evidence that significant biodegradation is occurring at the EJFDF. This evidence, combined with groundwater modeling results, suggests that natural attenuation may be an appropriate remedial alternative for the EJFDF site.

A mathematical model was used to simulate and predict BTEX plume migration. The groundwater modeling effort was restricted to aqueous-phase contamination in the caprock groundwater zone. Although the caprock groundwater at the EJFDF has been impacted by the 1971 MOGAS release, there is no evidence that the underlying basal aquifer has been impacted. The basal aquifer is isolated from the caprock groundwater by a thick sequence of impermeable confining strata. The local hydraulic gradient also acts to prevent caprock groundwater from entering the basal aquifer: the potentiometric surface of the confined basal aquifer is higher than that of the unconfined caprock aquifer.

5.3.3 Surface Water

The surface water pathway is of concern for the offsite area due to the potential for contaminated caprock groundwater from the EJFDF to discharge to the watercress ponds downgradient of the site, or to the Middle Loch of Pearl Harbor. However, as discussed in Section 3, results of the Phase II RI and previous investigations indicate that caprock groundwater does not reach the offsite ground surface or watercress ponds. No evidence of groundwater seeps or springs was identified during the Phase II RI surface water hydrology survey, or during surveys conducted during the Phase I RI. The low-permeability clay and silty clay units that overlie the caprock water-bearing zone in the offsite area appear to form a hydraulic barrier between the caprock groundwater and surface water in the agricultural/wetlands area. In addition, water table measurements indicate that the caprock water table is at least 2 feet below the bottom of the watercress ponds. The hydrogeologic characteristics of the offsite area indicate that the caprock water-bearing zone discharges at or beyond the Middle Loch shoreline.

The Phase I RI report presented a conservative analysis to show that dilution by clean basal groundwater from the artesian wells used to irrigate the watercress ponds would reduce contaminant concentrations to very low levels even if caprock groundwater did discharge to the agricultural area (Ogden 1996). Results of the analysis indicate that MOGAS constituent concentrations in offsite surface water are not likely to reach levels that would threaten human or ecological receptors.

As noted in the Phase I RI report, biodegradation, sorption, dilution, and dispersion will greatly reduce concentrations of MOGAS constituents before caprock groundwater discharges to Middle Loch. The report also evaluates the effects of dilution and mixing with seawater, and concludes that human and ecological receptors are not likely to be threatened by exposure to MOGAS constituents in Middle Loch (Ogden 1996).

No permanent surface water bodies exist within the EJFDF site boundary; therefore, contaminant transport via the surface water pathway in the onsite area is not a concern. Based on the low concentrations detected in onsite surface soil samples, contaminant concentrations in surface water runoff from the site are likely to be very low.

5.4 GROUNDWATER CONTAMINANT FATE AND TRANSPORT EVALUATION

The groundwater fate and transport evaluation presented here focuses on natural attenuation of aqueous-phase MOGAS constituents within the caprock water-bearing zone. As discussed in Section 5.3, the caprock water-bearing zone represents the major contaminant transport pathway at the EJFDF. Data acquired during the Phase II RI and previous investigations provide strong evidence that aqueous-phase MOGAS constituents in the caprock groundwater are attenuating naturally. The focus of the discussion is on the BTEX compounds, the predominant MOGAS constituents in the caprock groundwater. Also presented are results of groundwater modeling, using the BIOPLUME III model (EPA 1998) to simulate contaminant transport within the caprock water-bearing zone and predict the future extent of the EJFDF groundwater contaminant plume.

Natural attenuation may be an appropriate remedial alternative if degradation of site contaminants is occurring at rates sufficient to be protective of human health and the environment. Three lines of evidence are commonly used to demonstrate that biodegradation is occurring at a site and to evaluate natural attenuation as a remedial alternative (Weidemeier et al. 1995):

- Documented loss of contaminants at the field scale (contaminant concentration trends)
- Contaminant and geochemical analytical data (natural attenuation indicators)
- Microbiological evidence

To show that the total contaminant mass at a site is decreasing, statistically significant temporal and spatial contaminant concentration trends are evaluated in conjunction with parameters such as hydraulic conductivity, hydraulic gradient, and contaminant retardation factors. The first line of evidence was used to evaluate natural attenuation at the EJFDF.

To develop the second line of evidence, contaminant and electron acceptor concentration data are used to show that decreases in contaminant concentrations correlate with decreases in electron acceptor concentrations or increases in metabolic byproduct concentrations. This evidence can be used to estimate the biodegradation capacity of groundwater and thus confirm that electron acceptor concentrations are sufficient to allow microorganisms to degrade the dissolved contaminants. Geochemical data can also be used to identify the metabolic processes most likely to be responsible for observed biodegradation. The second line of evidence was used to evaluate natural attenuation at the EJFDF.

The third line of evidence, direct microbiological evidence, can be used to show that the indigenous population of microorganisms is capable of degrading site contaminants. To evaluate biodegradation rates specific to a particular site, soil samples from the site can be spiked with one or more of the hydrocarbons of concern (e.g., benzene) and incubated under appropriate conditions. Contaminant concentrations are then determined either directly or by measuring the production of metabolites. However, because microcosm studies are expensive, time consuming, and yield biodegradation rates that may not reflect actual field conditions, they should be undertaken only for sites at which there is considerable skepticism concerning biodegradation of fuel hydrocarbons (Weidemeier et al. 1995). Microcosm studies were not considered necessary to evaluate natural attenuation for the EJFDF.

Laboratory testing at the University of Hawaii in the early 1970s indicated that subsurface soil at the EJFDF contains bacteria and fungi known to be capable of degrading fuel hydrocarbons (Mau 1972).

5.4.1 Contaminant Concentration Trends and Natural Attenuation Rates

The maximum BTEX concentrations in EJFDF groundwater have historically been detected in samples collected from monitoring wells MW-2 and MW-15. MW-2 is immediately adjacent to UST S-26 (the MOGAS release point); MW-15 is approximately 250 feet downgradient of MW-2. As shown in Table 5-1, aqueous-phase BTEX concentrations at the EJFDF have decreased with time and with distance downgradient of the contaminant source area. Isopleth maps of total BTEX in caprock groundwater in August 1994, June–July 1998, and April–May 1999 are presented in Figures 4-4, 4-5, and 4-6, respectively.

Table 5-1: BTEX Concentrations at MW-2 and MW-15

Analyte	Mar. 1989		May 1992		Feb. 1993		Dec. 1993		Aug. 1994		June–July 1998	
	MW-2	MW-15	MW-2	MW-15	MW-2	MW-15	MW-2	MW-15	MW-2	MW-15	MW-2	MW-15
Benzene	2.90	—	4.70	1.90	2.60	1.40	1.80	0.32	3.00	1.00	0.55	0.56
Ethylbenzene	1.30	—	0.94	0.41	0.57	0.27	0.42	0.08	0.46	0.29	0.06	0.09
Toluene	0.87	—	0.44	0.04	0.24	0.03	0.17	0.01	0.20	0.02	0.04	0.01
Xylene (total)	5.00	—	2.45	0.07	1.05	0.03	0.62	0.01	0.50	0.03	0.05	0.01
Total BTEX	10.07	—	8.53	2.42	4.46	1.73	3.01	0.42	4.16	1.34	0.70	0.67

Note: All values in mg/L.

— = not available (MW-15 was installed in 1992).

The overall rate of contaminant attenuation is a function of all processes acting to reduce contaminant concentrations, including advection, dispersion, dilution from recharge, sorption, and biodegradation. To estimate a biodegradation rate, the components of attenuation caused by processes other than biodegradation must be subtracted from the overall attenuation rate. A guidance document produced by the Air Force Center for Environmental Excellence (AFCEE) presents two methods for estimating biodegradation rates from field data (Wiedemeier et al. 1995). The first method involves the use of a conservative tracer. The second method was derived by Buscheck and Alcantar (1995).

Attenuation of groundwater contaminant concentrations over time can often be described using a first-order rate constant. First-order decay is described by the following ordinary differential equation:

$$\frac{dC}{dt} = -hC$$

Where:

C = the concentration at time t

h = the overall attenuation rate (first-order rate constant)

The solution to this differential equation is:

$$C = C_0 e^{-ht}$$

Where:

C_0 = the concentration at time zero

Conservative Tracer Method. The portion of contaminant attenuation caused by processes other than biodegradation can be accounted for by monitoring concentrations of a conservative tracer with physical and chemical properties similar to the contaminants of concern at various locations within the groundwater plume. Trimethylbenzene (TMB) resists biodegradation under anaerobic conditions and has volatilization and sorptive characteristics similar to those of BTEX. Moreover, since TMB is already present in many fuels (including gasoline) in sufficient quantities to be detectable when the fuel is dissolved in water, TMB does not have to be added from an external source (Weidemeier et al. 1995).

The following equation can be used to estimate the concentration of the compound of interest expected at Point B (located downgradient of Point A) if biodegradation were the only factor responsible for attenuation (Weidemeier et al. 1995):

$$C_{Bcorr} = C_B(TMB_A/TMB_B)$$

Where:

C_{Bcorr} = corrected contaminant concentration at Point B (downgradient point)

C_B = measured contaminant concentration at Point B

TMB_A = measured concentration of TMB at Point A (upgradient point)

TMB_B = measured concentration of TMB at Point B

When the corrected contaminant concentration at Point B, C_{Bcorr} , is substituted for C in the relation $C = C_0e^{-ht}$, the equation becomes:

$$C_{Bcorr} = C_Ae^{-kt}$$

Where:

C_A = measured concentration at Point A (upgradient point)

k = first-order biodegradation rate

Since the effects of advection, dispersion, dilution, and sorption have been removed, the rate constant in this equation is now the first-order biodegradation rate (k), not the overall attenuation rate (h). The first-order biological decay rate constant can be calculated by solving the equation for k .

The travel time (t) between two points is given by:

$$t = x / V_e$$

Where:

x = distance along the flow path between the two points, and

V_e = retarded solute velocity

A first-order rate constant can be estimated from TMB-corrected data by plotting the natural logarithms of TMB-corrected concentrations for several points along the flow path versus travel time. If the data points lie approximately along a straight line, the relationship is approximately first-order, and a regression analysis can be performed to obtain the equation of the best-fit straight line. The slope of the best-fit line represents the estimated first-order decay rate.

One objective of the Phase II RI groundwater investigation was to evaluate biodegradation rates using the conservative tracer method; therefore, all groundwater samples collected at the EJFDF during the Phase II RI sampling effort were analyzed for TMB. However, TMB was detected at only one sampling point: MW-2 (1,2,4 TMB: 0.007 mg/L; 1,3,5 TMB: 0.002 mg/L). Biodegradation rates can not be evaluated by the conservative tracer method without data from at least two sampling points.

Buscheck and Alcantar Method. The Buscheck and Alcantar (1995) method involves plotting the natural logarithms of contaminant concentrations versus distance downgradient. The slope of the best-fit regression line is used to solve for the first-order biodegradation rate term (k) in the differential equation for one dimensional, steady-state contaminant transport. The method accounts for the advection, dispersion, retardation, and biodegradation terms in the following analytical solution of the contaminant transport equation:

$$k = \frac{V_c}{4\alpha_x} \left(\left[1 + 2\alpha_x \left(\frac{m}{V_x} \right) \right]^2 - 1 \right)$$

Where:

- k = first-order biodegradation rate
- V_c = retarded contaminant velocity in the x-direction
- α_x = dispersivity
- m/V_x = slope of the regression line fit to a plot of the natural logarithm of contaminant concentration versus distance downgradient along the flow path

Biodegradation rates for the EJFDF BTEX plume were estimated by the Buscheck and Alcantar (1995) method. Measured contaminant concentration data were used in conjunction with parameters such as hydraulic conductivity, dispersivity, hydraulic gradient, and contaminant retardation factors. Field data from each sampling event since May 1992 (such as the June–July 1998 data shown in Table 5-2) were evaluated to estimate average site-specific first-order biodegradation rates for each BTEX compound. Benzene, toluene, ethylbenzene, and xylene concentrations observed along the plume centerline flow path (MW-2 to MW-15 to MW-4) were used as input data.

Table 5-2: BTEX Concentrations Detected along Centerline Flow Path, June–July 1998

	Monitoring Well		
	MW-2	MW-15	MW-4
Approximate distance from source (feet)	0	250	750
Benzene	0.554	0.555	<0.010
Toluene	0.041	0.006	<0.010
Ethylbenzene	0.063	0.088	0.002
Total Xylene	0.047	0.007	<0.010

All values in mg/L.

The following are first-order biodegradation rates were estimated by the Buscheck and Alcantar (1995) method for the EJFDF BTEX plume:

- Benzene: –0.51 per year
- Toluene: –0.20 per year
- Ethylbenzene: –0.09 per year
- Xylene: –0.16 per year

Discussion. The flux of “fresh” electron acceptors through the caprock water-bearing zone appears to be the limiting factor for biodegradation at the EJFDF. Caprock groundwater seepage velocities are low due to the low hydraulic conductivity of the caprock strata (2×10^{-4} cm/sec or less in the onsite area); therefore, fresh electron acceptors enter the contaminant source area relatively slowly. Low groundwater velocity results in a slow-moving plume in which biodegradation is limited by electron acceptor availability (Wiedemeier et al. 1995).

Although BTEX biodegradation rates at the EJFDF are relatively low compared to other sites, aqueous-phase hydrocarbons migrate very slowly through the caprock water-bearing zone, allowing sufficient time for biodegradation to reduce concentrations to very low levels well within the site boundary. The long contaminant travel times are a function of both low groundwater seepage velocities and retardation due to reversible sorption to soil particles. Since the electron acceptors are inorganic and, therefore, are not retarded, the electron acceptors move downgradient more quickly than the contaminants. Fresh electron acceptors are continually entering the contaminant plume. This results in a contaminant plume that continues to decrease in both concentration and area over time; this has been observed at the EJFDF as illustrated in the distributions of ICs over time, presented in Section 4.

The variations in biodegradation rates between compounds may be due to differences in the rates at which the microbial population at the EJFDF is able to metabolize benzene, toluene, ethylbenzene, and xylene. As discussed below, sulfate-reducing microorganisms may be responsible for degrading a significant portion of the dissolved hydrocarbons at the EJFDF. A large population of sulfate-reducing microorganisms may have developed in response to the high sulfate concentrations in caprock groundwater upgradient of the source area.

5.4.2 Natural Attenuation Indicators

To evaluate natural attenuation processes at the site, all groundwater samples collected during the Phase II RI were analyzed for a wide range of hydrogeochemical parameters. Hydrogeochemical data can be used to evaluate the potential for biodegradation at a site, identify the processes most likely to

be responsible for biodegradation, and assess the magnitude and extent of contaminant attenuation. Biodegradation within a plume of aqueous-phase hydrocarbons depends on the availability of oxidized species capable of acting as terminal electron acceptors. Oxygen, nitrate, sulfate, ferric iron, and carbon dioxide are the electron acceptors most commonly utilized by microorganisms to degrade dissolved hydrocarbons. Because oxygen is usually depleted quickly by aerobic microbial activity within the most heavily contaminated regions of an aquifer, anaerobic microorganisms are often responsible for mineralizing most of the hydrocarbons (Weidemeier et al. 1995).

As microorganisms oxidize hydrocarbons, electron acceptors are reduced. The extent and magnitude of biodegradation can therefore be assessed by monitoring either the depletion of electron acceptors or the production of electron acceptor metabolites. For example, aerobic biodegradation is usually assessed by monitoring dissolved oxygen (DO) concentrations, while to assess biodegradation by ferric iron reduction, the metabolite (ferrous iron) is monitored.

The spatial distribution and concentrations of electron acceptors (DO, nitrate, and sulfate) and metabolic by-products (methane and ferrous iron), coupled with the observed reduction in BTEX concentrations with both time and with distance downgradient of the source area, provides strong evidence that BTEX in EJFDF caprock groundwater is being degraded by microbially mediated processes.

Dissolved Oxygen. Isopleth maps depicting June–July 1998 and April–May 1999 caprock aquifer DO concentrations are presented in Figure 5-2 and Figure 5-3.

Microorganisms utilize DO (the most thermodynamically favored electron acceptor) during aerobic degradation of aqueous-phase hydrocarbons. DO concentrations upgradient of the plume can be used to estimate the mass of hydrocarbons that can be biodegraded by aerobic processes. According to the stoichiometry of the aerobic BTEX biodegradation reaction, approximately 3.1 mg of DO is consumed for each 1.0 mg of BTEX mineralized to carbon dioxide and water (Weidemeier et al. 1995). This estimate is conservative because it does not account for the mass of BTEX used to produce cell mass. Anaerobic microorganisms (obligate anaerobes) generally cannot function until aerobic microorganisms have reduced DO concentrations to less than about 0.5 mg/L.

DO concentrations in EJFDF groundwater show an inverse correlation with BTEX concentrations. DO concentrations detected at MW-20 (located outside the area impacted by the MOGAS release) were 4.25 mg/L in June–July 1998 and 5.42 mg/L in April–May 1999. The DO level at MW-20 is considered representative of background conditions. DO concentrations are below 0.1 mg/L in the plume area, indicating that aerobic microorganisms have depleted DO to oxidize hydrocarbons associated with the MOGAS release. In the offsite area downgradient of the plume, DO concentrations were as high as 5.64 mg/L (MI-12) and 4.09 mg/L (MI-2).

Nitrate. Isopleth maps depicting June–July 1998 and April–May 1999 caprock aquifer nitrate concentrations are presented in Figure 5-4 and Figure 5-5.

After DO has been nearly depleted, denitrifying microorganisms can degrade aqueous-phase hydrocarbons using nitrate as an electron acceptor. Nitrate concentrations upgradient of the plume can be used to estimate the mass of hydrocarbons that can be biodegraded by denitrification. According to the stoichiometry of BTEX biodegradation by denitrification, approximately 4.9 mg of nitrate is consumed for each 1.0 mg of BTEX mineralized (Weidemeier et al. 1995). This estimate is conservative because it does not account for the mass of BTEX used to produce cell mass.

Nitrate concentrations in EJFDF groundwater show a strong inverse correlation with BTEX concentrations, indicating that aqueous-phase hydrocarbons within the plume area are degraded by denitrification. Background conditions are represented by the 3.0 mg/L and 3.1 mg/L nitrate concentrations detected at MW-20 and MW-19, respectively. Nitrate concentrations decrease to levels below the detection limit (0.1 mg/L) in the plume area. Maximum nitrate concentrations detected downgradient of the plume were 4.8 mg/L (MI-9) and 2.0 mg/L (MI-24).

Ferrous Iron. Isopleth maps depicting June–July 1998 and April–May 1999 caprock aquifer ferrous iron concentrations are presented in Figure 5-6 and Figure 5-7.

Microorganisms that use ferric iron as an electron acceptor can also degrade aqueous-phase hydrocarbons. As the hydrocarbons are degraded, ferric iron is reduced to ferrous iron, which is soluble in water. Therefore, ferrous iron concentrations can be used as a biodegradation indicator. According to the stoichiometry of BTEX biodegradation by ferric iron reduction, approximately 21.8 mg of ferrous iron is produced for each 1.0 mg of BTEX mineralized (Weidemeier et al. 1995). This estimate is conservative because it does not account for the mass of BTEX used to produce cell mass.

Ferrous iron levels detected in EJFDF groundwater were highest in the heart of the BTEX plume, suggesting that iron-reducing microorganisms have degraded aqueous-phase hydrocarbons in this area. Maximum ferrous iron levels detected at MW-2 and MW-15 were 4.5 mg/L and 4.4 mg/L, respectively. Ferrous iron was not detected at the background sampling locations (MW-20 and MW-19).

Sulfate. Isopleth maps depicting June–July 1998 and April–May 1999 caprock aquifer sulfate concentrations are presented Figure 5-8 and Figure 5-9.

After DO, nitrate, and bioavailable ferric iron reach low concentrations, biodegradation may continue as aqueous-phase hydrocarbons are oxidized by sulfate-reducing microorganisms. According to the stoichiometry of BTEX biodegradation by sulfate reduction, approximately 4.7 mg of sulfate is consumed for each 1.0 mg of BTEX mineralized (Weidemeier et al. 1995). This estimate is conservative because it does not account for the mass of BTEX used to produce cell mass. Sulfate reduction will produce a sulfate distribution that is inversely correlated with the BTEX distribution.

Very high sulfate concentrations were detected in caprock groundwater outside the BTEX plume in June–July 1998. The sulfate concentration detected at MW-20 was 100 mg/L. At MW-14 (approximately 300 feet upgradient of UST S-26), sulfate was detected at 70.3 mg/L. Sulfate concentrations were less than 10 mg/L within the plume. At MW-2, the sulfate concentration was only 0.27 mg/L. In the offsite area downgradient of the plume, sulfate concentrations reach levels as high as 98.2 mg/L (MI-11), and 93.7 mg/L (MI-9). The large difference between sulfate concentrations within the plume and outside the plume suggests that groundwater entering the contaminant source zone can supply enough sulfate to degrade large quantities of aqueous-phase hydrocarbons.

Methane. Isopleth maps depicting June–July 1998 and April–May 1999 caprock aquifer methane concentrations are presented in Figure 5-10 and Figure 5-11.

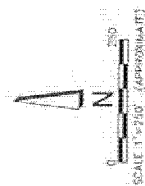
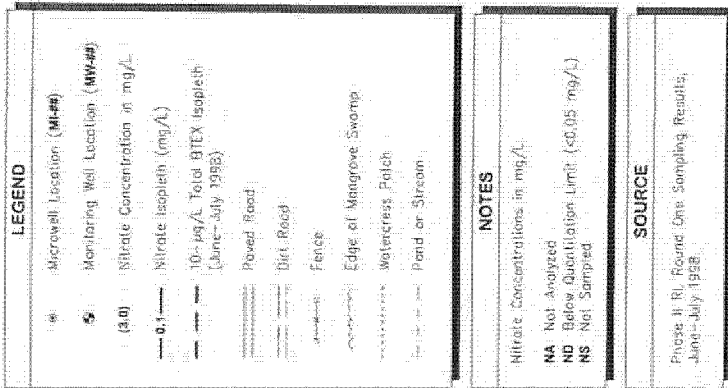
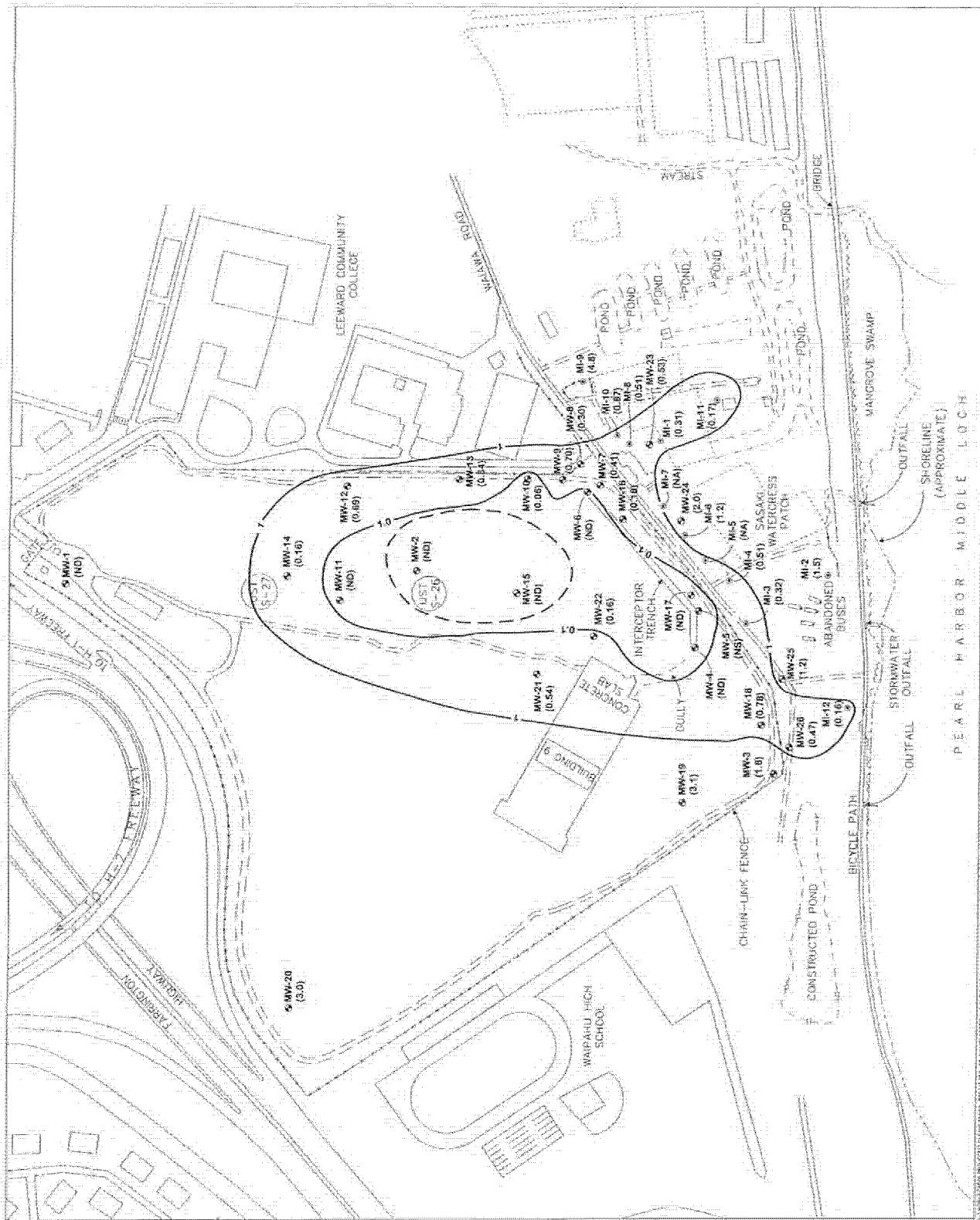


Figure 5-4
Nitrate Concentrations
in Groundwater, June-July 1998
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii



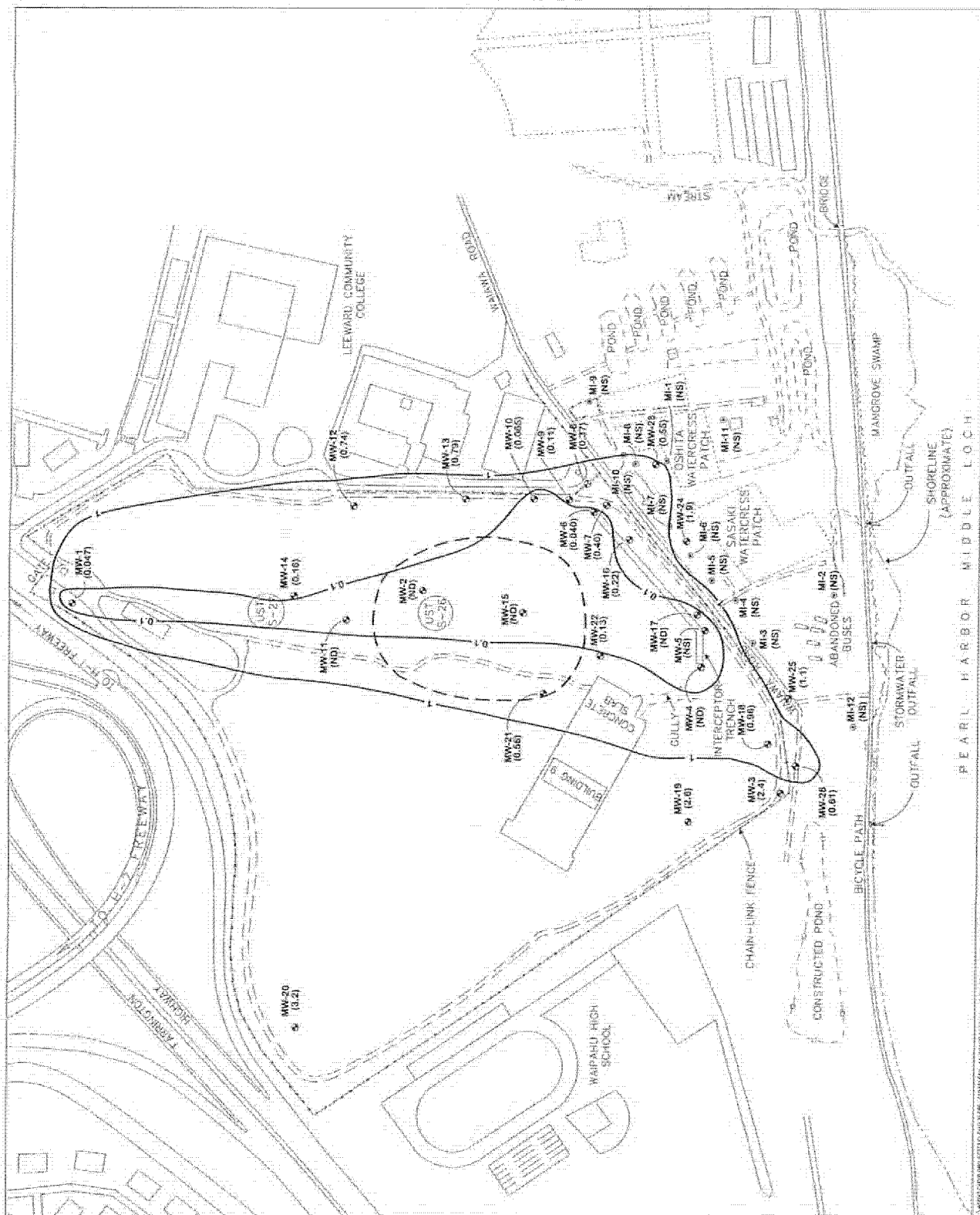
LEGEND	
●	Monitoring Well Location (MW-##)
○	Monitoring Well Location (MW-##)
(0.16)	Nitrate Concentration in mg/L
— 0.1 —	Nitrate Isopleth (mg/L)
— 10 —	10-μg/L Total BTEX Isopleth (April-May 1999)
=====	Paved Road
=====	Dirt Road
=====	Fence
=====	Edge of Mangrove Swamp
=====	Watercress Patch
=====	Pond or Stream

NOTES	
Nitrate Concentrations in mg/L	
ND Below Quantitation Limit (40.035 mg/L)	
NS Not Sampled	

SOURCE	
Phase II RI, Round Two Sampling Results, April-May 1999	



Figure 5-5
Nitrate Concentrations
in Groundwater, April-May 1999
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



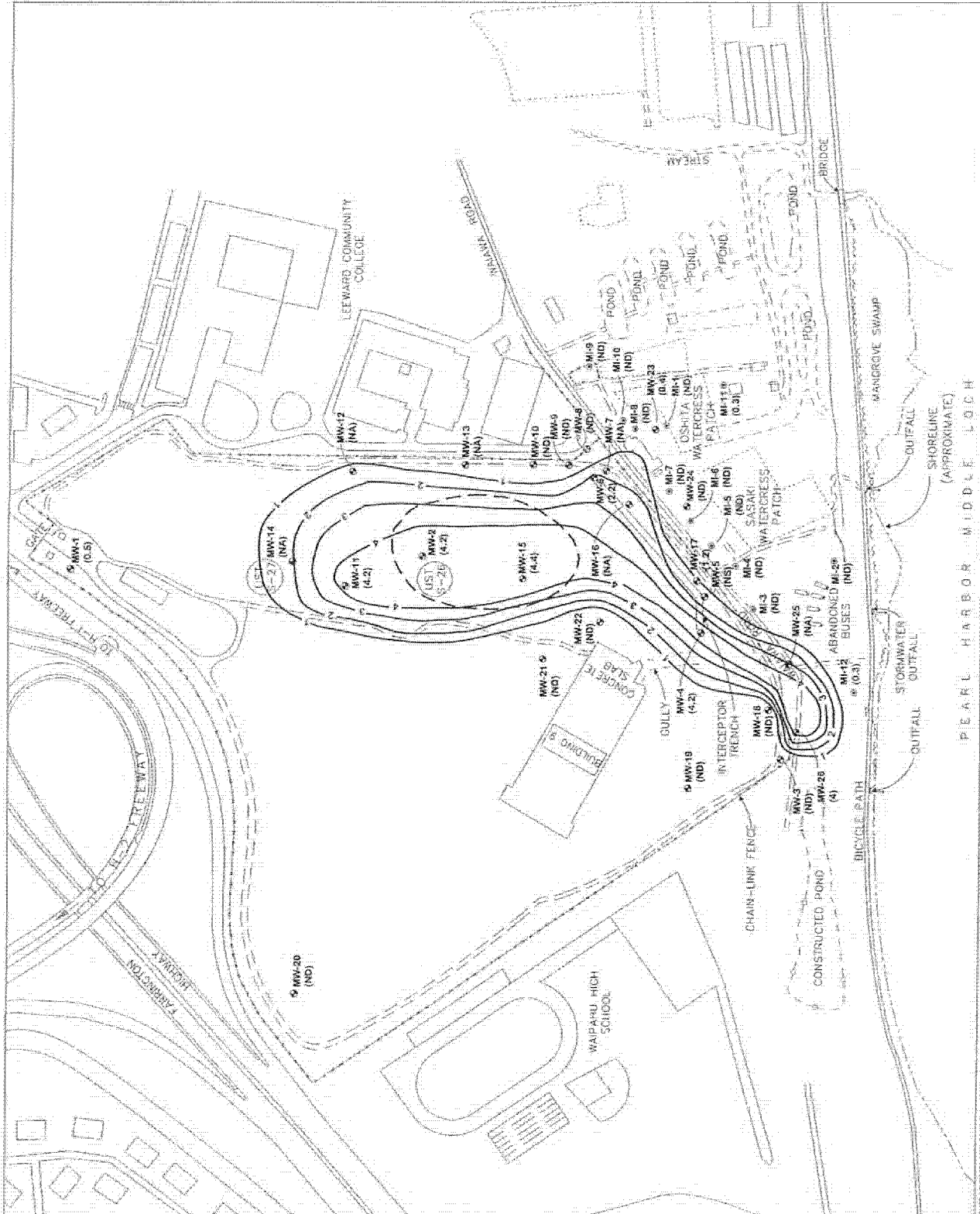
LEGEND	
●	Monitoring Well Location (MW-#)
○	Monitoring Well Location (MW-#)
(4.2)	Ferrous Iron Concentration in mg/L
—	Ferrous Iron Isopleth (mg/L)
---	10-µg/L Total BTEX Isopleth (June-July 1998)
==	Paved Road
---	Dirt Road
---	Fence
---	Edge of Mangrove Swamp
---	Watercress Patch
---	Pond or Stream

NOTES	
Ferrous Iron Concentrations in mg/L	
NA	Not Analyzed
ND	Not Detected (field test—no quantitation limit)
NS	Not Sampled

SOURCE	
Phase II RI, Round One Sampling Results, June-July 1998	



Figure 5-6
Ferrous Iron Concentrations
in Groundwater, June-July 1998
Phase II RI
Ewa Junction Fuel Drilling Facility
Pearl Harbor, Oahu, Hawaii



LEGEND	
●	Microwell Location (MI-##)
⊙	Monitoring Well Location (MW-##)
(4.0)	Ferrous Iron Concentration in mg/L
1	Ferrous Iron Isopleth (mg/L)
10-µg/L Total BTEX Isopleth (April-May 1999)	
=====	Paved Road
=====	Dirt Road
=====	Fence
=====	Edge of Mangrove Swamp
=====	Watercress Patch
=====	Pond or Stream

NOTES	
Ferrous Iron Concentrations in mg/L	
ND	Not Detected (field test - no quantitation limit)
NS	Not Sampled

SOURCE	
Phase II RI, Round Two Sampling Results (April-May 1999)	

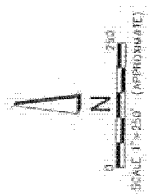
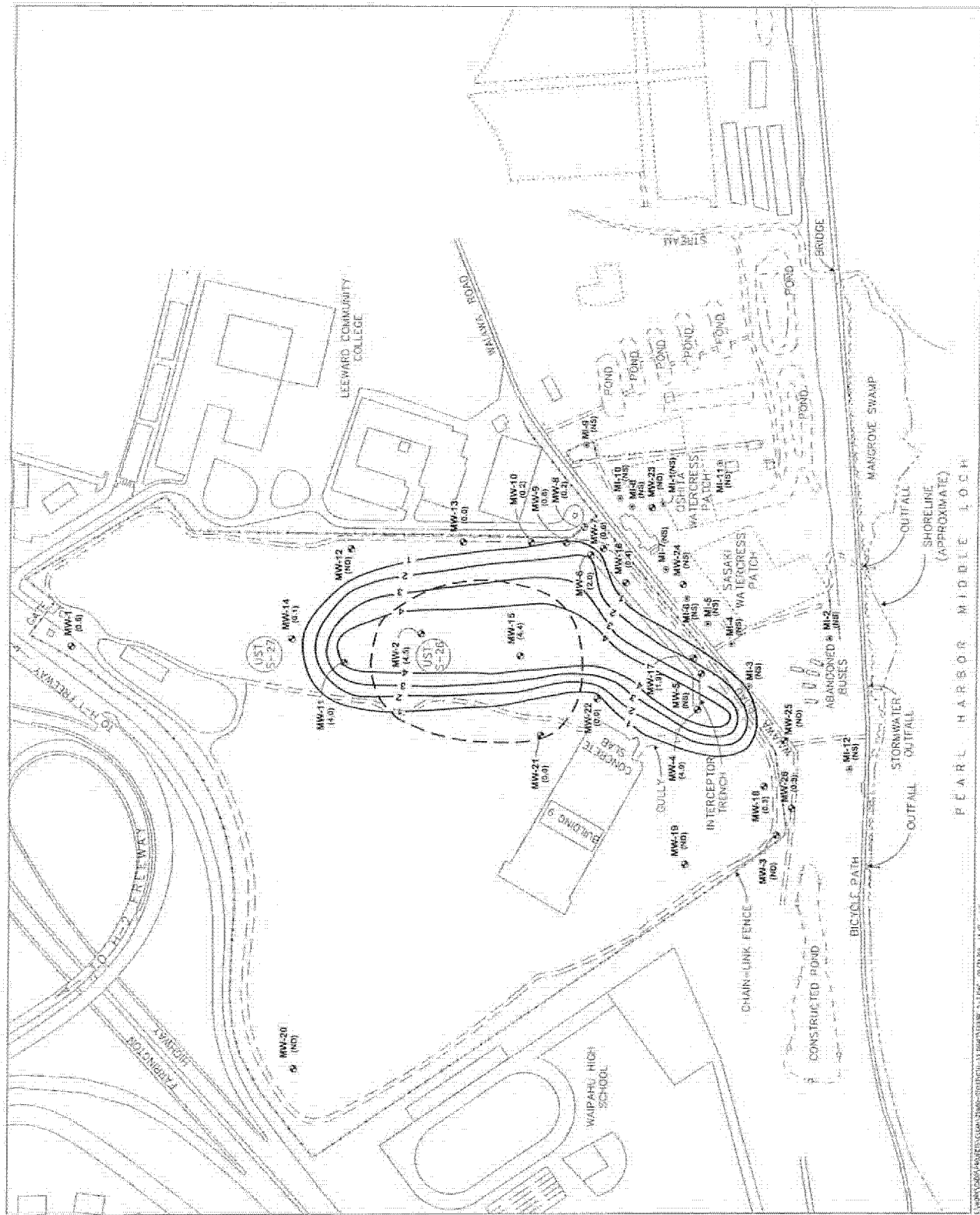
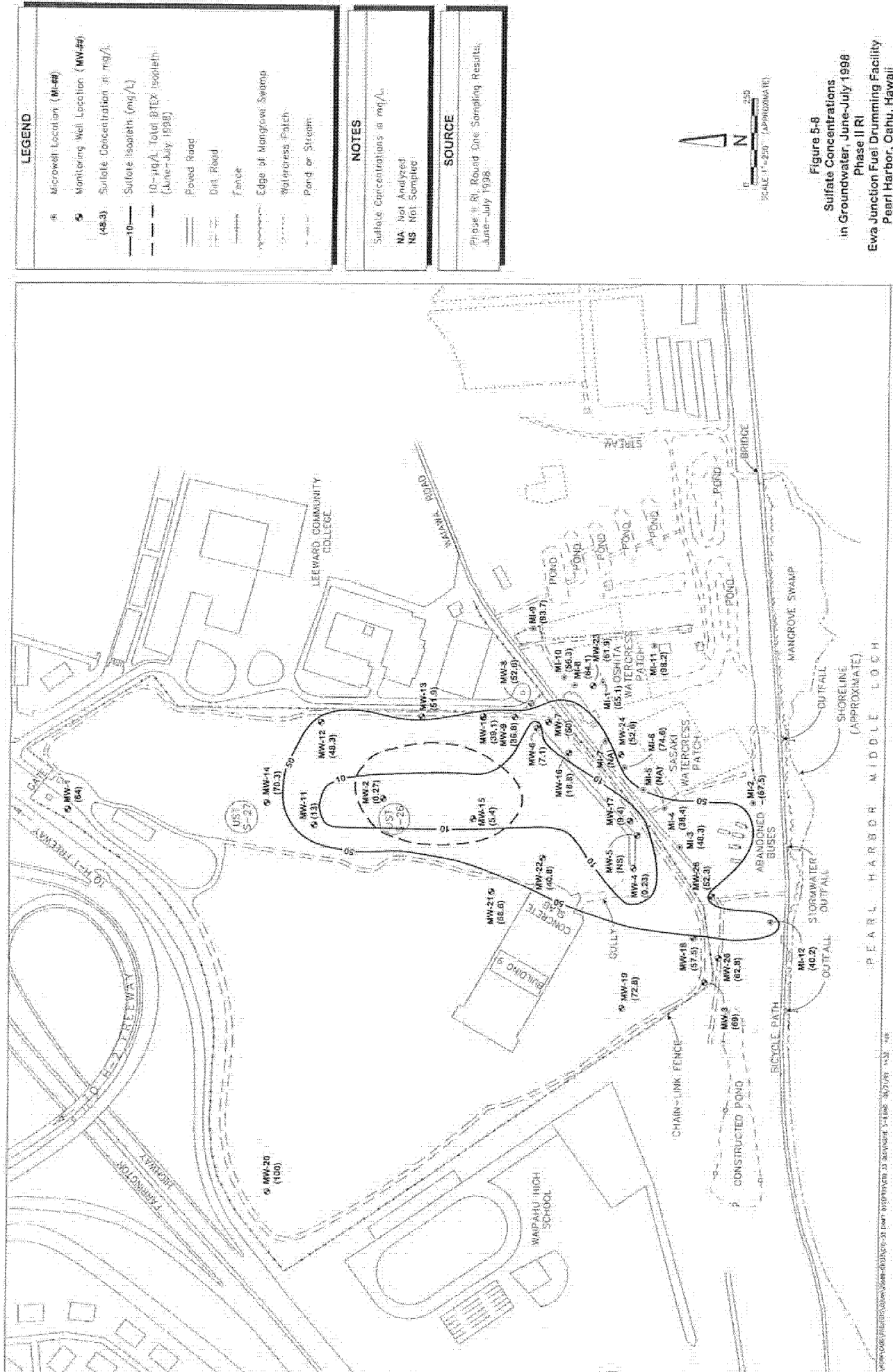
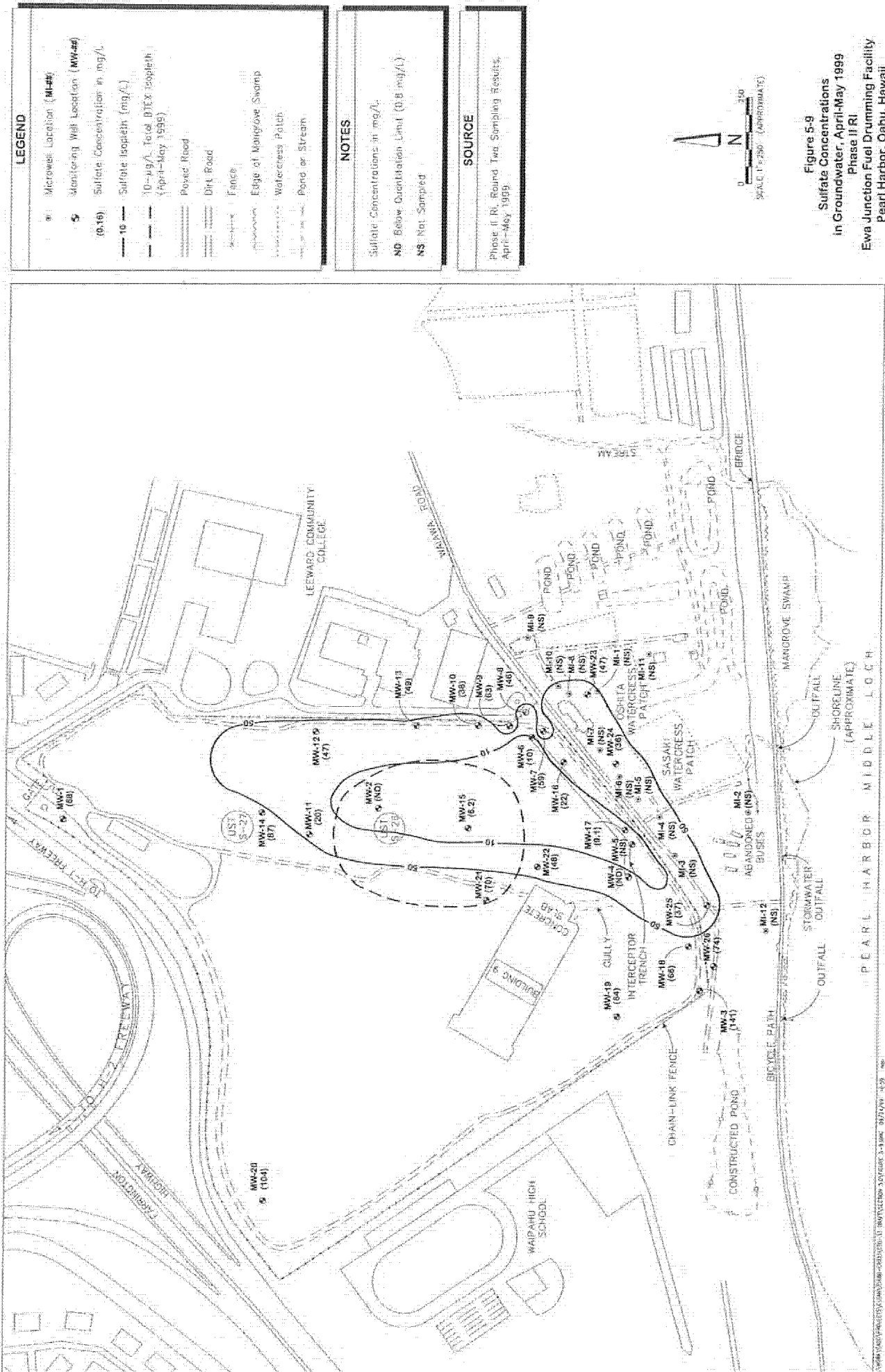


Figure 5-7
 Ferrous Iron Concentrations
 in Groundwater, April-May 1999
 Phase II RI
 Ewa Junction Fuel Drumming Facility
 Pearl Harbor, Oahu, Hawaii







Methanogenic microorganisms may also contribute to hydrocarbon degradation after DO, nitrate, and ferric iron have reached low concentrations. Methane is produced when carbon dioxide is used as an electron acceptor. Methane is not a component of liquid fuels; therefore, elevated concentrations of dissolved methane in groundwater impacted by a fuel release indicate that hydrocarbons have been degraded by methanogenic microorganisms. According to the stoichiometry of the methanogenic BTEX biodegradation reaction, approximately 0.78 mg of methane is produced for each 1.0 mg of BTEX mineralized (Weidemeier et al. 1995). This estimate is conservative because it does not account for the mass of BTEX used to produce cell mass.

Dissolved methane levels detected in EJFDF groundwater in June–July 1998 were highest in the heart of the BTEX plume, suggesting that methanogenic microorganisms have degraded aqueous-phase hydrocarbons in this area. The maximum methane concentration (2.5 mg/L) was detected at MW-2. Background methane concentrations were very low. The methane concentration detected at MW-20 was only 2.1×10^{-4} mg/L. At MW-14, methane was detected at only 5.7×10^{-4} mg/L. In the offsite area downgradient of the plume, methane concentrations decrease to levels similar to upgradient background concentrations.

Other Parameters Affecting Biodegradation Rates. Factors such as groundwater temperature, pH, alkalinity, and the concentrations of essential nutrients, such as nitrogen and phosphorus, can affect biodegradation rates. However, for most petroleum release plumes, the rate of in situ biodegradation is controlled by the distribution and availability of electron acceptors (EPA 1998).

Groundwater Temperature. Bacterial growth rates and biodegradation rates tend to increase with groundwater temperature. Within the 5°–25°C range, hydrocarbon biodegradation rates roughly double for every 10°C increase in temperature (Weidemeier et al. 1995). Groundwater temperatures at the EJFDF are relatively high and show little variation throughout the year due to relatively small seasonal temperature variations. Caprock groundwater temperatures measured in June–July 1998 averaged 26.7°C.

pH. The optimal pH range for BTEX degrading microorganisms is 6–8. In June–July 1998, the average pH of caprock groundwater at the EJFDF was approximately 6.5.

Alkalinity. Alkalinity maintains favorable pH levels by buffering against pH changes that can occur during aerobic and anaerobic biodegradation of organic compounds. Because carbon dioxide is produced when organic compounds are oxidized, areas contaminated with petroleum hydrocarbons exhibit higher total alkalinity than background areas. Average total alkalinity of EJFDF groundwater in June–July 1998 was approximately 280 mg/L (as calcium carbonate). As expected, alkalinity tended to be relatively high in the monitoring wells in or near the source area, and low in background areas. Total alkalinity at MW-2 and MW-15 (in and near the contaminant source area) was 588 mg/L and 431 mg/L, respectively, while total alkalinity at MW-20 (background) was only 159 mg/L.

Redox Potential. Oxidation/reduction (redox) potential indicates the relative tendency of a solution to accept or transfer electrons. The redox potential of groundwater ranges from –400 millivolts (mV) to 800 mV. Microorganisms that utilize electron acceptors with lower oxidizing potentials (such as sulfate and carbon dioxide) tend to become dominant after electron acceptors with higher oxidizing potentials have been reduced, causing a large drop in redox potentials. Table 5-3 shows typical redox conditions found in groundwater when different electron acceptors are used (Weidemeier et al. 1995).

Table 5-3: Redox Potentials for Various Electron Acceptors

Reaction	Electron Acceptor	Metabolic By-Products	Redox Potential
Aerobic respiration	Oxygen	Carbon dioxide	+820
Denitrification	Nitrate	Carbon dioxide, nitrogen	+740
Iron III reduction	Ferric iron	Ferrous iron	-50
Sulfate reduction	Sulfate	Sulfide	-220
Methanogenesis	Carbon dioxide	Methane	-240

Redox potentials measured at the EJFDF in June–July 1998 ranged between –280 mV and 444 mV. The highest redox potential was measured at MW-1 (approximately 900 feet upgradient of UST S-26). Redox potentials measured within the BTEX plume at MW-2 and MW-15 in June–July 1998 were –280 mV and –250 mV, respectively; this suggests that sulfate reduction and methanogenesis are likely the dominant biodegradation reactions in the contaminant source area and immediately downgradient.

Biodegradation Capacity of EJFDF Groundwater. The stoichiometry of the microbially mediated reactions (aerobic respiration, denitrification, sulfate and iron reduction, and methanogenesis) can be used to estimate the potential hydrocarbon mass removal, or “biodegradation capacity,” of groundwater flowing through the contaminant source zone. The biodegradation capacity can then be compared to the maximum hydrocarbon concentrations detected at the site (Weidemeier et al. 1995).

First, total concentrations of each electron acceptor available for biological reactions are estimated by (1) calculating the difference between upgradient concentrations and source zone concentrations for oxygen, nitrate, and sulfate; and (2) evaluating the production of metabolic by-products (ferrous iron and methane) in the contaminant source zone.

Next, using stoichiometry, a utilization factor is estimated for each biodegradation reaction. Utilization factors are ratios of the mass of an electron acceptor consumed, or metabolic by-product produced, per unit mass of dissolved hydrocarbon degraded. Weidemeier et al. (1995) provide utilization factors based on the degradation of combined BTEX constituents. The biodegradation capacity that can be attributed to an individual electron acceptor is calculated by dividing the available concentration of the electron acceptor by the corresponding utilization factor. The total estimated biodegradation capacity (in BTEX concentration units) is the sum of the biodegradation capacities associated with each individual electron acceptor. Table 5-4 shows the calculations used to estimate the biodegradation capacity of EJFDF caprock groundwater.

Table 5-4: EJFDF Caprock Groundwater Biodegradation Capacity Estimate

Natural Attenuation Indicator	Average Upgradient Concentration (mg/L)	Average Source Area Concentration (mg/L)	Uptake Concentration (mg/L)	Utilization Factor ^a	Biodegradation Capacity (mg/L of BTEX)
DO	4.25	0.1	4.15	3.14	1.32
Nitrate	3.0	0.1	2.9	4.9	0.59
Sulfate	100.0	0.03	99.97	4.7	21.27
Ferrous iron	^b	4.2	4.2	21.8	0.19
Methane	^b	2.5	2.5	0.78	3.2
Total biodegradation capacity:					26.57

^a Utilization factor = mg uptake species / mg BTEX degraded

^b Not used to determine uptake concentration.

The maximum total BTEX concentration detected in EJFDF groundwater since 1992 is approximately 8.5 mg/L (detected at MW-2 in May 1992). As shown in Table 5-2, only about 0.7 mg/L of total BTEX was detected at MW-2 in June–July 1998. As shown in Table 5-4, the total biodegradation capacity of groundwater flowing into the EJFDF contaminant source area is estimated at 26.6 mg/L, suggesting that more than enough biodegradation capacity is available to degrade BTEX in EJFDF groundwater. (The median biodegradation capacity for 28 AFCEE natural attenuation sites is 28.5 mg/L [Weidemeier et al. 1995]). The biodegradation capacity estimate is conservative because the utilization factors do not account for microbial cell mass production; i.e., they assume that all the BTEX is completely mineralized, while in reality some of the BTEX is used to produce cell mass. Cell mass production takes up less of the electron acceptor than complete mineralization. The biodegradation capacity estimates indicate that sulfate reduction is the dominant reaction responsible for biodegradation of BTEX in EJFDF groundwater. Methanogenesis also appears to be an important process.

5.4.3 Groundwater Modeling

The EJFDF BTEX plume was simulated using the BIOPLUME III groundwater model (EPA 1998). Objectives of the modeling effort were to predict the spatial extent and concentration of the BTEX plume and help assess potential risks to downgradient biological receptors posed by migration of contaminants in the caprock groundwater. The model is described, the data input and calibration process is summarized, and modeling results and conclusions are presented. Appendix M presents a more detailed description of the model, site-specific input parameters, model calibration, sensitivity analysis, modeling results (with figures), and conclusions.

Model Description. BIOPLUME III is a two-dimensional, finite difference model designed to simulate natural attenuation of organic contaminants in groundwater. It was developed by the EPA (Subsurface Protection and Remediation Division, National Risk Management Research Laboratory, Robert S. Kerr Environmental Research Center, Ada, Oklahoma) and the AFCEE (Brooks Air Force Base, Texas) (EPA 1998). Biodegradation reactions are simulated using one of three options: first-order decay, instantaneous reaction, or Monod kinetics. The model also accounts for the effects of advection, dispersion, sorption, and ion exchange.

EJFDF groundwater modeling utilized the BIOPLUME III first-order decay method. Modeling results obtained using this method closely matched plume characteristics (extent and concentration) observed during the Phase II RI and previous sampling events. Average first-order biodegradation rates for the BTEX compounds in EJFDF groundwater were calculated from field data using the Buscheck and Alcantar (1995) method. The calculated biodegradation rates varied between –0.09 per year (ethylbenzene) and –0.51 per year (benzene). The rate calculation methodology is described and calculated site-specific rates are presented in Section 5.4.1.

The first-order decay method uses the exponential decay relationship:

$$C = C_0 e^{kt}$$

Where:

- C = concentration of the chemical after time t
- C_0 = starting concentration
- k = first-order decay rate

A first-order decay rate can also be expressed as a half-life (*HL*):

$$HL = -0.693 / k$$

5.4.3.1 MODEL INPUT AND CALIBRATION

Input parameters were based primarily on site-specific data. Where site-specific data were not available, conservative assumptions were made based on widely accepted literature values. Due to the conservative input parameters, the actual decrease in contaminant mass due to natural attenuation is likely to exceed model predictions. The benzene, toluene, ethylbenzene, and xylene plumes were simulated separately to account for parameters such as biodegradation rates, retardation, and dispersivity, which vary depending on the compound.

Calibration to the hydraulic and chemical conditions observed in the field is a key step in numerical groundwater modeling. A properly calibrated model is capable of predicting future hydraulic conditions and contaminant concentrations. The EJFDF simulations were calibrated by adjusting hydraulic parameters, boundary conditions, and stresses to approximate observed field conditions. Input parameters are discussed below. Appendix M provides detailed information regarding the input parameters used to calibrate the model and simulate the EJFDF BTEX plumes.

Grid Design. The modeling grid selected for the EJFDF was 1,800 feet by 1,800 feet. Each grid cell was 100 feet by 100 feet; the grid was 18 cells wide and 18 cells long. The modeling grid covers an area of 3.24 million square feet, or approximately 75 acres, and covers the entire EJFDF site and the offsite area between the site and Pearl Harbor Middle Loch.

Simulation Period. The time span of each simulation was 60 years from the date of the release (March 1971). The 60-year period was used to ensure that the time span was long enough to simulate reduction of benzene, toluene, ethylbenzene, and xylene concentrations in EJFDF caprock groundwater to very low levels (on the order of 0.010 mg/L or less).

Groundwater Elevation and Gradient. Caprock water table elevation data from August 1998 were used as model input. The thickness of the caprock saturated zone was estimated at 50 feet. As a conservative approach, recharge due to rainfall infiltration was not included in the model.

BTEX Concentrations. Maximum BTEX concentrations observed during each of the six sampling events between 1989 and 1998 were used to calibrate the model. Because MW-2 and MW-15 are located in the heart of the plume, BTEX concentrations detected at these two wells were the primary calibration criteria. MW-2 is located immediately adjacent to UST S-26 (on the northeast edge of the tank). MW-15 is located near the plume centerline, approximately 25 feet downgradient of MW-2. Table 5-5 and Table 5-6 list the maximum concentrations detected at MW-2 and MW-15, respectively.

Table 5-5: Maximum BTEX Concentrations at MW-2, 1989–1998

Analyte	Mar 1989	May 1992	Feb 1993	Dec 1993	Aug 1994	Jun–July 1998
Benzene	2.90	4.70	2.60	1.80	3.00	0.55
Ethylbenzene	1.30	0.94	0.57	0.42	0.46	0.06
Toluene	0.87	0.44	0.24	0.17	0.20	0.04
Xylene, total	5.00	2.45	1.05	0.62	0.50	0.05
Total BTEX	10.07	8.53	4.46	3.01	4.16	0.70

All values in mg/L.

Table 5-6: Maximum BTEX Concentrations at MW-15, 1989–1998

Analyte	Mar 1989	May 1992	Feb 1993	Dec 1993	Aug 1994	Jun–Jul 1998
Benzene	—	1.90	1.40	0.32	1.00	0.56
Ethylbenzene	—	0.41	0.27	0.08	0.29	0.09
Toluene	—	0.04	0.03	0.01	0.02	0.01
Xylene, total	—	0.07	0.03	0.01	0.03	0.01
Total BTEX	—	2.42	1.73	0.42	1.34	0.67

All values in mg/L.

— = not available (MW-15 was installed in 1992).

Nine injection wells were used to simulate the contaminant source. Injection rates were set to maintain a constant total injection rate of 7.7 cubic feet per day over the 60-year simulations. The low injection rate minimized the effect on the simulated water table. Benzene, toluene, ethylbenzene, and xylene injection concentrations and injection periods were varied by trial and error until the simulation predictions closely matched observed concentrations.

Hydraulic Conductivity. Accurate estimates of hydraulic conductivity (K) are important to quantify groundwater flow velocities, define groundwater residence times, and evaluate the quantity of electron-acceptor-rich groundwater entering the contaminant source zone from upgradient locations. Hydraulic conductivity input parameters were based on values obtained from slug and pump testing reported in the Phase I RI (Ogden 1996). Input K values ranged from 2.2×10^{-4} feet per second in the onsite area down to 2.2×10^{-6} feet per second in the offsite area. In the onsite area, lenses of higher conductivity sand and gravel are interbedded with silty clay, while stratigraphy in the offsite area is dominated by clay and silty clay with a few thin sand and gravel layers. The K values were distributed to the grid using the BIOPLUME III kriging tool.

The general shapes of the simulated BTEX plumes are similar to the actual plume shapes observed over the sampling events since 1992, indicating that the model accurately simulates actual flow conditions. Like the actual BTEX plume, the simulated plumes tend to spread out laterally as they approach the downgradient site boundary. Results obtained during the calibration process suggest the lateral spreading is primarily a function of decreased hydraulic conductivity in the offsite area relative to the onsite area.

Biodegradation Rates. As discussed in Section 5.4.1, field data from the EJFDF site were used to estimate first-order biodegradation rates for each of the BTEX compounds. The rates were estimated using the benzene, toluene, ethylbenzene, and xylene concentrations observed along the plume centerline flow path—MW-2 to MW-15 to MW-4—for each sampling event. The following are average first-order biodegradation rates (k) and half lives (HL) estimated for the BTEX compounds at the EJFDF:

- Benzene: $k = -0.51$ per year, $HL = 1.36$ years
- Toluene: $k = -0.20$ per year, $HL = 3.47$ years
- Ethylbenzene: $k = -0.09$ per year, $HL = 7.70$ years
- Xylene: $k = -0.16$ per year, $HL = 4.33$ years

Dispersivity. Longitudinal dispersivity values reported in the literature for alluvial sediments range from 0.1 to 200 feet (Walton 1988). Dispersivity values specific to the EJFDF site were estimated

from field data by plotting concentrations of each BTEX compound versus distance along the centerline of the plume for each of the sampling events since 1992. In accordance with the AFCEE technical protocol (Weidemeier et al. 1995), longitudinal dispersivity values were estimated as one-tenth of the distance between the spill source and the centroid of each curve. The estimates were then averaged to generate the following longitudinal dispersivity input parameters:

- Benzene: 22.5 ft
- Toluene: 11.5 ft
- Ethylbenzene: 28.6 ft
- Xylene: 8.8 ft

Retardation. Reversible sorption to organic carbon particles within the soil matrix tends to retard the transport velocity of BTEX compounds relative to the groundwater seepage velocity. Retardation factors (R) were estimated for each compound as:

$$R = 1 + D_b K_d / N_e$$

Where:

- R = ratio of groundwater seepage velocity to contaminant transport velocity
- D_b = soil bulk density (gm/cm³)
- K_d = distribution coefficient (L/kg)
- N_e = effective porosity

Soil bulk density and effective porosity are properties of the matrix of the water-bearing zone. K_d is the product of the fraction of organic carbon in the matrix (f_{oc}) and the organic carbon partitioning coefficient (K_{oc}) specific to the chemical compound.

The soil bulk density input value, 1.88 g/cm³, is from an estimate reported in the Phase I RI report (Ogden 1996). The estimate is based on typical values for the soil types that occur at the site. The f_{oc} value was estimated as 0.002 based on the results of laboratory analyses of 32 soil boring samples collected during the Phase I RI. This value is consistent with typical values reported in the literature for the soil types that occur at the site. The K_{oc} input values listed below are based on values recommended in the AFCEE technical protocol (Weidemeier et al. 1995):

- Benzene: $K_{oc} = 79$ L/kg
- Toluene: $K_{oc} = 190$ L/kg
- Ethylbenzene: $K_{oc} = 468$ L/kg
- Xylene: $K_{oc} = 395$ L/kg

Due to the difficulty involved in determining N_e , the N_e input value estimate was based on the range of accepted literature values for the soil types within the shallow saturated zone at the EJFDF. Freeze and Cherry (1979) give the following ranges for N_e : sand, 0.25–0.50; silt, 0.35–0.50; clay, 0.40–0.70. To be conservative, a relatively low value, 0.30, was used as the N_e input value for EJFDF modeling. This estimate is conservative because lower N_e values result in higher seepage velocities. The parameter values listed above yield the following K_d and R factors:

- Benzene: $K_o = 0.158 \text{ L/kg}$, $R = 1.99$
- Toluene: $K_o = 0.379 \text{ L/kg}$, $R = 3.38$
- Ethylbenzene: $K_o = 0.935 \text{ L/kg}$, $R = 6.87$
- Xylene: $K_o = 0.790 \text{ L/kg}$, $R = 5.95$

5.4.3.2 SENSITIVITY ANALYSIS

The purpose of a sensitivity analysis is to evaluate the effects of uncertainties in input parameter estimates on model results. After the "base-case" has been established by calibrating the model, model input parameters are varied individually over a series of simulations. The sensitivity of the model to a particular input parameter is then quantified by observing the magnitude of changes in plume characteristics (such as concentration and extent). The sensitivity of the EJFDF groundwater model was evaluated by varying the porosity, dispersivity, hydraulic conductivity, distribution coefficient, and biodegradation rate input parameters and observing the effects on the simulated benzene plume.

Results of the sensitivity analysis are presented in Appendix M. In summary, the model was very sensitive to changes in the first-order biodegradation rate; it was much less sensitive to hydrogeologic and contaminant-specific parameters such as porosity, hydraulic conductivity, dispersivity, and the distribution coefficient.

The analysis shows that errors in hydrogeologic and contaminant-specific parameters would have to be very significant before they have a great effect on the modeling results. However, when biodegradation rate input values are significantly increased or decreased, the simulated plume concentration distribution and extent are very different from the plume characteristics observed in the field. This suggests that the biodegradation rate estimates used in the modeling effort are representative of actual field conditions.

5.4.3.3 MODEL RESULTS

The BIOPLUME III model was run under steady-state conditions for simulation periods of 60 years. Although the benzene, toluene, ethylbenzene, and xylene plumes actually overlap, the migration of each contaminant was simulated separately. Parameters such as retardation factors and biodegradation rates are chemical-specific quantities; this approach thus gives a more realistic simulation of contaminant migration than modeling total BTEX. In addition, by modeling the plumes separately, it is possible to predict where and when cleanup criteria associated with each compound may be exceeded.

The benzene, toluene, ethylbenzene, and xylene plumes were modeled using the compound-specific first-order biodegradation rates estimated from field data by the method of Buscheck and Alcantar (1995). To better understand the effect of biodegradation on contaminant distribution and concentration, each plume was also modeled with the biodegradation rate set to zero.

The figures presented in Appendix M depict the simulated benzene, toluene, ethylbenzene, and xylene plumes. The figures presented in this section depict only the simulated benzene plume. Benzene is more mobile in the aqueous phase than the other BTEX compounds, and poses a greater threat to human health (as evidenced by the low DOH and EPA action levels for benzene in drinking water).

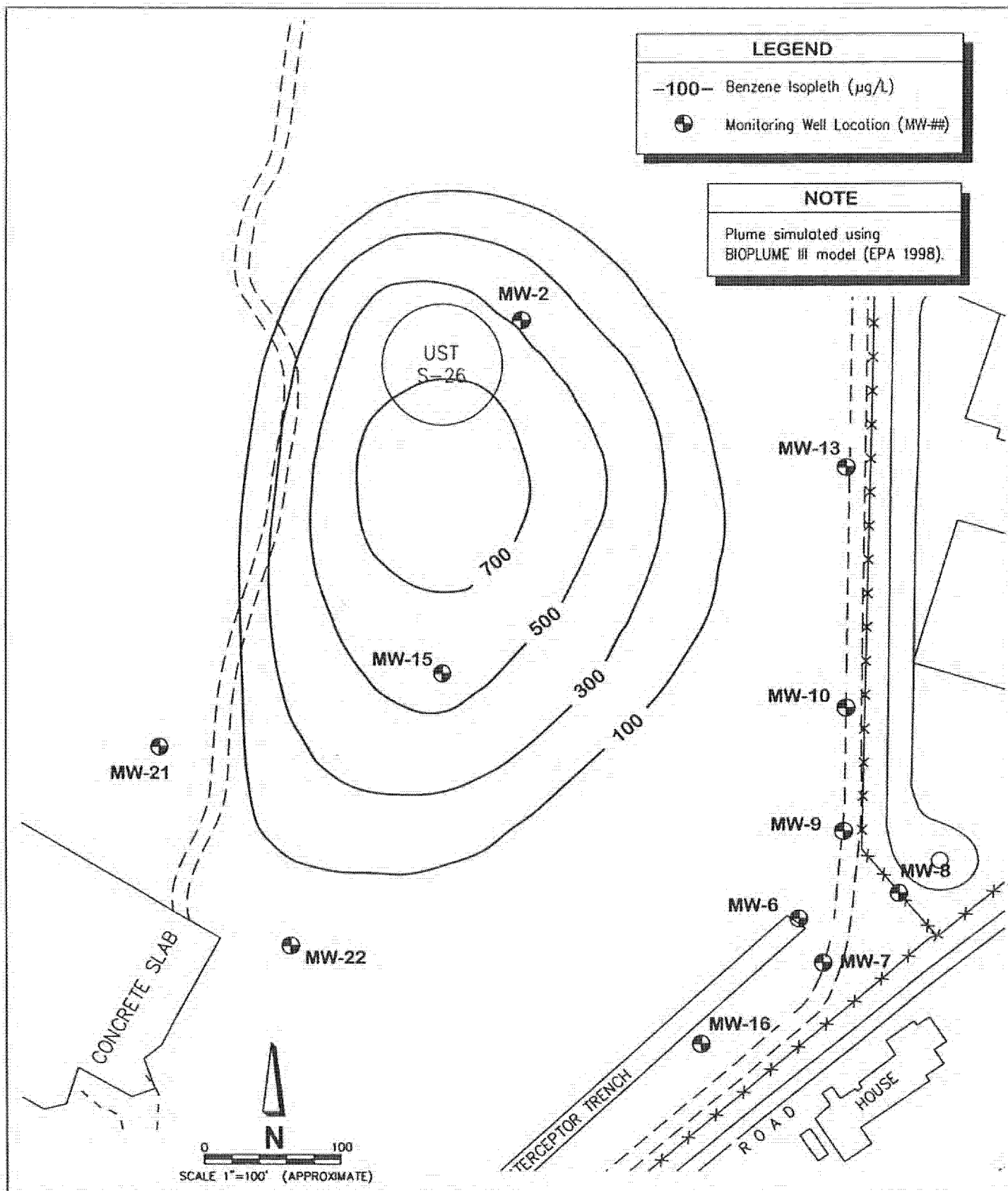
Benzene Plume. Benzene is more hydrophilic and soluble than the other BTEX compounds; therefore, benzene is more mobile in groundwater than the other compounds. However, due to a

relatively high biodegradation rate ($HL = 1.36$ years), aqueous-phase benzene at the EJFDF is less mobile than might be expected. As discussed above, field data indicate that benzene is more readily biodegraded than the other BTEX compounds in EJFDF groundwater.

Benzene concentrations predicted by the model closely match concentrations detected over the six sampling events between 1989 and 1998. Benzene concentrations predicted for MW-2 and MW-15 at 27.5 years after the release (summer 1998) are approximately 0.5 mg/L and 0.6 mg/L, respectively. Benzene concentrations detected at MW-2 and MW-15 in June–July 1998 are 0.554 mg/L and 0.555 mg/L, respectively. The maximum concentration predicted for the simulated plume is approximately 0.8 mg/L. As defined by a 0.1-mg/L isopleth, the simulated plume covers an area of approximately 2.75 acres and extends about 400 feet downgradient of MW-2. The simulated 27.5-year plume covers a greater area than the actual plume (based on 1998 field data), indicating that the simulation represents a conservative estimate. Simulated benzene concentrations at the downgradient site boundary (approximately 750 feet from MW-2) are on the order of 10^{-4} mg/L or less. The simulated 27.5-year benzene plume is depicted in Figure 5-12.

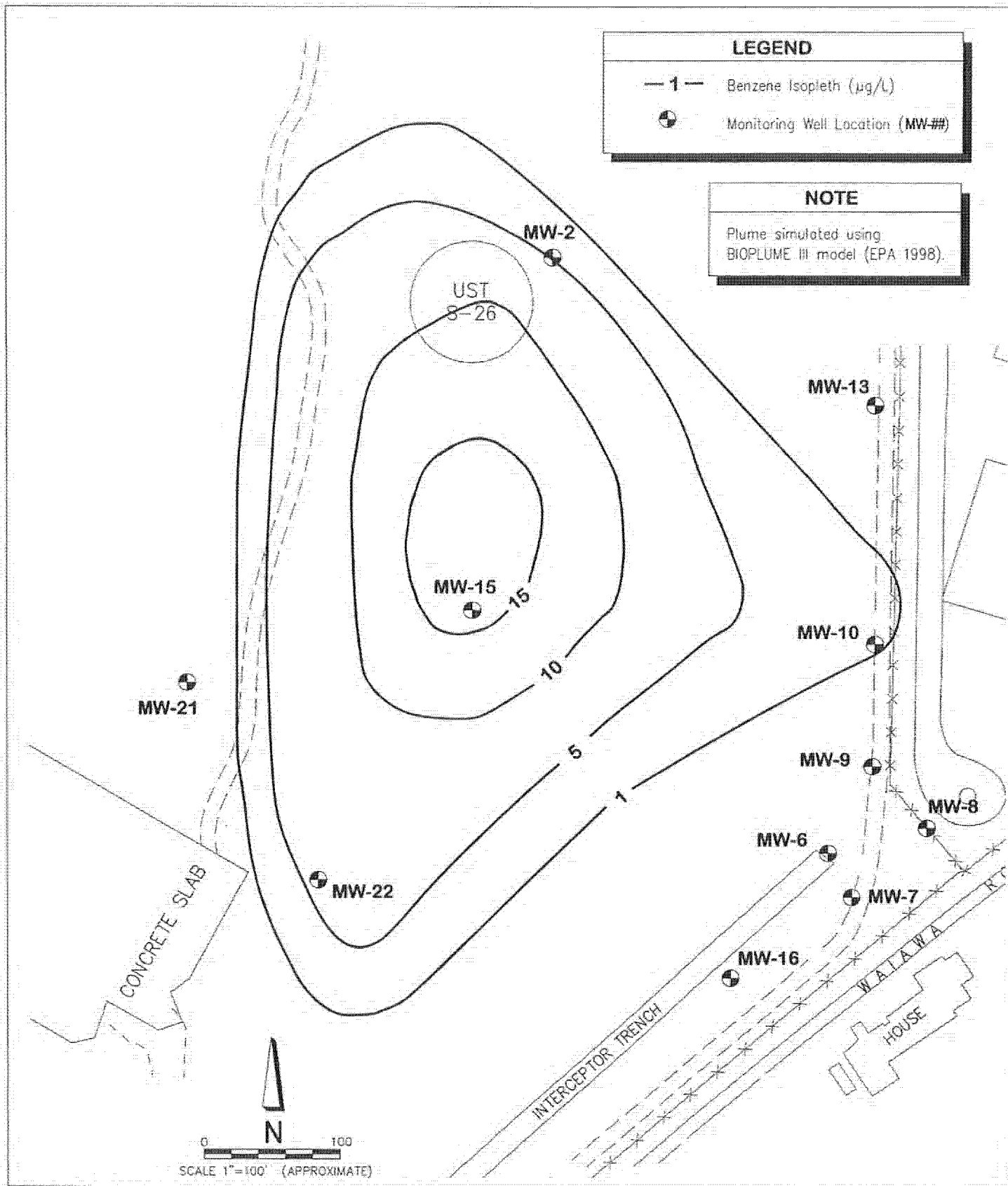
As shown in Figure 5-13, the predicted concentrations and extent of the benzene plume 10 years later (i.e., 37.5 years after the release [summer 2008]) show a dramatic decrease. The plume appears to be detaching from the source while migrating downgradient at very low concentrations. The maximum benzene concentration predicted for this time step is approximately 0.015 mg/L (a decrease of more than one order of magnitude from 1998 levels). The benzene concentration predicted for MW-2 is approximately 0.005 mg/L, while the concentration predicted for MW-15 is approximately 0.015 mg/L. As defined by a 0.01-mg/L isopleth, the simulated plume covers an area of approximately 1.3 acres and extends about 350 feet downgradient of MW-2. Predicted benzene concentrations at the downgradient site boundary are on the order of 10^{-4} mg/L or less.

To visualize the effect of biodegradation on plume concentrations and extent, the biodegradation rate was set to zero and the other parameters, including contaminant injection rates, were not changed. As shown in Figure 5-14, with no biodegradation, the maximum predicted benzene concentration for the 27.5-year time step is more than 25 mg/L (compared to 0.8 mg/L with biodegradation active). Concentrations above 3 mg/L are predicted to extend approximately 600 feet downgradient of MW-2. Benzene concentrations at the downgradient site boundary are approximately 0.1 mg/L. With biodegradation active, predicted concentrations for the 27.5-year time step decrease to 0.1 mg/L within approximately 400 feet of MW-2. Model results (including figures that illustrate the simulated benzene plume) are presented in Appendix M.



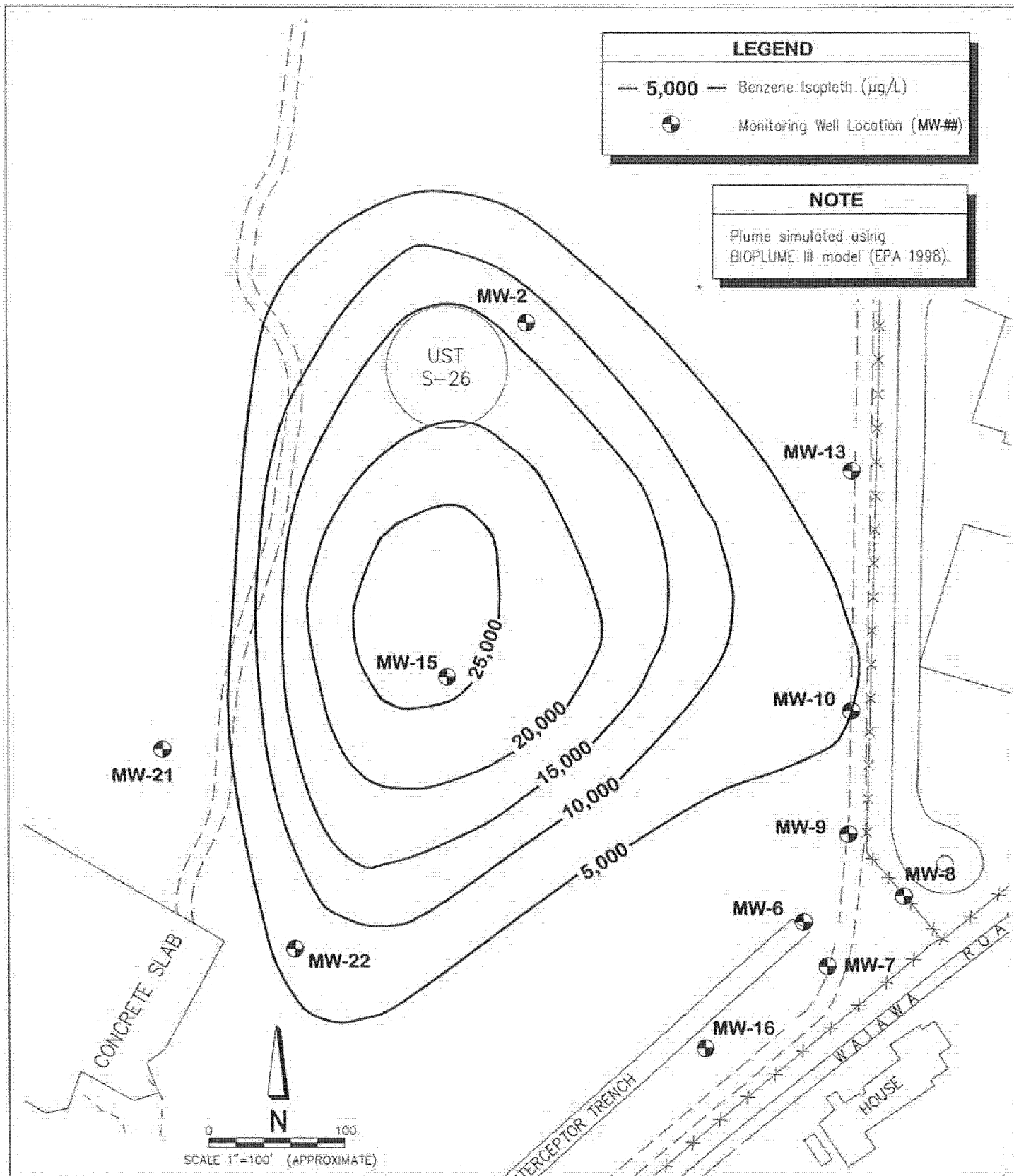
L:\BORD\CADD\PROJECTS\CLEAN\25680-C7033\CTO-33 DRAFT\SECTION 5.0\FIGURE 5-12.DWG 10/30/00 12:28 km

Figure 5-12
 Simulated Benzene Plume at 27.5 Years
 After MOGAS Release (1998)
 Phase II RI
 Ewa Junction Fuel Drumming Facility
 Pearl Harbor, Oahu, Hawaii



L:\WORK\CADD\PROJECTS\CLEAN\25680-CT033\CT0-33 DRAFT\SECTION 5.0\FIGURE 5-13.DWG 09/23/99 15:00 nob

Figure 5-13
Simulated Benzene Plume at 37.5 Years
After MOGAS Release (2008)
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii



L:\WORK\CADD\PROJECTS\CLEAN\25680-CT033\CTO-33 DRAFT\FIGURE 5-12.DWG 09/20/99 15:18 nob

Figure 5-14
Simulated Benzene Plume at 27.5 Years
After MORGAS Release (1998)
with Biodegradation Rate Set to Zero
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

Toluene Plume. Toluene is relatively hydrophilic and moderately soluble; therefore, it is relatively mobile in the aqueous phase. The site-specific toluene *HL* (3.47 years) indicates that toluene biodegrades more slowly in EJFDF groundwater than benzene, but more quickly than ethylbenzene or xylene.

Predicted toluene concentrations are similar to the concentrations detected over the first five sampling events. However, for the 27.5-year time step (corresponding to the June–July 1998 sampling event), the calibrated model slightly over-predicted toluene concentrations. The simulation predicted MW-2 and MW-15 toluene concentrations of approximately 0.08 mg/L and 0.04 mg/L, respectively. Actual toluene concentrations detected at MW-2 and MW-15 in June–July 1998 are somewhat lower—only 0.041 mg/L and 0.006 mg/L, respectively. The simulated concentration trend thus appears to represent a conservative forecast. The maximum concentration predicted for the simulated toluene plume at 27.5 years is 0.129 mg/L. As defined by a 0.1-mg/L isopleth, the simulated plume covers an area of approximately 0.6 acre, and extends approximately 200 feet downgradient of MW-2. Simulated toluene concentrations at the downgradient site boundary are on the order of 10^{-6} mg/L or less.

Ten years later (i.e., 37.5 years after the release), the maximum predicted toluene concentration is only 0.014 mg/L. The toluene concentration predicted for MW-2 is less than 0.004 mg/L, while the concentration predicted for MW-15 is approximately 0.012 mg/L. As defined by a 0.01-mg/L isopleth, the simulated plume covers an area of approximately 0.76 acre and extends less than 300 feet downgradient of MW-2. Predicted toluene concentrations at the downgradient site boundary are again on the order of 10^{-6} mg/L or less.

With the biodegradation rate set to zero, the maximum predicted toluene concentration for the 27.5-year time step is 1.15 mg/L (compared to 0.129 mg/L with biodegradation active), and concentrations above 1 mg/L are predicted to extend approximately 200 feet downgradient of MW-2. Maximum toluene concentrations at the site boundary are on the order of 10^{-5} mg/L. Model results (including figures that illustrate the simulated toluene plume) are presented in Appendix M.

Ethylbenzene Plume. Ethylbenzene is moderately soluble but less mobile in groundwater than the other BTEX compounds due to its greater tendency to adsorb to organic carbon. The site-specific ethylbenzene *HL* (7.70 years) indicates that ethylbenzene in EJFDF groundwater biodegrades more slowly than the other BTEX compounds. Modeling results suggest the ethylbenzene plume is likely to persist (at low concentrations) longer than the benzene, toluene, or xylene plumes.

The calibrated model closely matches ethylbenzene concentrations over the first five sampling events, but it over-predicted concentrations for the 27.5-year time step (summer 1998). Between the August 1994 (23.5 year) and June–July 1998 (27.5 year) sampling events, actual ethylbenzene concentrations detected at MW-2 and MW-15 decreases sharply—from 0.46 mg/L and 0.49 mg/L to 0.063 mg/L and 0.088 mg/L, respectively. The simulation predicted MW-2 and MW-15 ethylbenzene concentrations of approximately 0.3 mg/L and 0.4 mg/L, respectively, for the 27.5-year time step. The simulated ethylbenzene concentration trend therefore appears to represent a conservative forecast. The maximum concentration predicted for the simulated 27.5-year ethylbenzene plume is 0.586 mg/L. As defined by a 0.1-mg/L isopleth, the simulated plume covers approximately 2.3 acres and extends nearly 400 feet downgradient of MW-2. Simulated ethylbenzene concentrations at the downgradient site boundary are on the order of 10^{-5} mg/L or less.

Ten years later (i.e., 37.5 years after the release), the maximum predicted ethylbenzene concentration is 0.312 mg/L. The predicted MW-2 concentration is less than 0.14 mg/L, while the predicted MW-15 concentration is approximately 0.24 mg/L. Although the maximum concentration is lower, the simulated plume, as defined by a 0.1-mg/L isopleth, still covers approximately

2.3 acres, extending approximately 370 feet downgradient of MW-2. Predicted ethylbenzene concentrations at the downgradient site boundary are on the order of 10^{-4} mg/L or less.

After the 37.5-year time step, the plume area enclosed by the 0.1-mg/L ethylbenzene isopleth shows a marked decrease. At 48 years, the 0.1-mg/L isopleth encloses an area of only 0.9 acre and the maximum concentration is down to 0.136 mg/L.

With the biodegradation rate set to zero, the maximum predicted ethylbenzene concentration for the 27.5-year time step is 2.21 mg/L (compared to 0.586 mg/L with biodegradation active), and concentrations above 1 mg/L are predicted to extend approximately 300 feet downgradient of MW-2. Maximum ethylbenzene concentrations at the downgradient site boundary are on the order of 10^{-5} mg/L. Model results (including figures that illustrate the simulated ethylbenzene plume) are presented in Appendix M.

Xylene Plume. The xylene isomers are slightly less soluble than ethylbenzene, but are more mobile in groundwater than ethylbenzene since they do not adsorb as strongly to organic carbon. The site-specific xylene *HL* (4.33 years) indicates that xylene in EJFDF groundwater biodegrades more slowly than benzene or toluene, but more quickly than ethylbenzene.

The calibrated model closely matches xylene concentrations over the first five sampling events, but over-predicted concentrations for the 27.5-year time step (summer 1998). Between the August 1994 (23.5 year) and June–July 1998 (27.5 year) sampling events, actual xylene concentrations detected at MW-2 and MW-15 decrease sharply—from 0.50 mg/L and 0.029 mg/L, to 0.047 mg/L and 0.007 mg/L, respectively. Simulated xylene concentrations for MW-2 and MW-15 are approximately 0.24 mg/L and 0.05 mg/L, respectively, for the 27.5-year time step. The simulated xylene concentration trend, therefore, appears to represent a conservative forecast. The maximum concentration predicted for the simulated 27.5-year xylene plume is 0.313 mg/L. As defined by a 0.1-mg/L isopleth, the simulated plume covers approximately 1.8 acres and extends approximately 260 feet downgradient of MW-2. Simulated xylene concentrations at the downgradient site boundary are on the order of 10^{-7} mg/L or less.

Ten years later (i.e., 37.5 years after the release), the maximum predicted xylene concentration is 0.043 mg/L. The predicted MW-2 concentration is approximately 0.022 mg/L, while the predicted MW-15 concentration is approximately 0.028 mg/L. The simulated plume, as defined by a 0.01-mg/L isopleth, covers approximately 2.6 acres, extending approximately 350 feet downgradient of MW-2. Predicted xylene concentrations at the downgradient site boundary are on the order of 10^{-7} mg/L or less.

With the biodegradation rate set to zero, the maximum predicted xylene concentration for the 27.5-year time step is 3.21 mg/L (compared to 0.313 mg/L with biodegradation active), and concentrations above 1 mg/L are predicted to extend approximately 250 feet downgradient of MW-2. Maximum xylene concentrations at the downgradient site boundary were on the order of 10^{-6} mg/L. Model results (including figures that illustrate the simulated xylene plume) are presented in Appendix M.

5.4.3.4 GROUNDWATER MODELING CONCLUSIONS

The modeling results suggest that the marked decrease in hydrocarbon concentrations in EJFDF caprock groundwater observed over the years since the MOGAS release can be attributed primarily to biodegradation. When biodegradation rates were set to zero, the simulations yielded BTEX concentrations much higher than the actual observed concentrations. In addition, with no

biodegradation, the simulated BTEX plumes extended much farther downgradient than the actual plumes.

The modeling results also suggest that most of the BTEX contamination currently remaining in EJFDF caprock groundwater represents aqueous-phase BTEX that partitioned into groundwater during the period when free product was in direct contact with the caprock water table. Residual soil contamination appears to contribute only a small portion of the overall mass of aqueous-phase BTEX remaining at the site. To achieve simulated concentrations approaching the low levels observed during recent sampling events, injected BTEX concentrations had to be decreased to very low levels approximately 10 years into the simulations. BTEX that remains within vadose zone soil in the contaminant source area appears to partition into the aqueous phase at a very low rate.

As discussed in Section 5.4.2, electron acceptor concentrations upgradient of the source area are high enough to provide approximately 26.6 mg/L (in BTEX concentration units) of biodegradation capacity. Furthermore, due to BTEX retardation, the electron acceptor plume tends to move downgradient faster than the BTEX plume. The result, as confirmed by groundwater sampling results obtained during the Phase II RI and previous investigations, is a contaminant plume that continues to decrease in both concentration and area over time. These observations suggest the rate at which BTEX is removed from the aqueous phase by biodegradation is likely to greatly exceed the rate at which BTEX is partitioned into the aqueous phase from vadose zone soil.

Modeling results indicate that BTEX concentrations in on site caprock groundwater are likely to reach very low levels within the next decade. (The simulations represent a conservative scenario—simulated 27.5-year time step [summer 1998] BTEX concentrations are higher than concentrations detected in June–July 1998 and April–May 1999.) BTEX concentrations detected in MW-2 and MW-15 have already decreased to levels well below the cleanup criteria specified for the caprock water-bearing zone (see Section 8.1.4). Modeling results are also consistent with the observation that BTEX concentrations reach extremely low levels well before the downgradient site boundary; therefore, aqueous-phase hydrocarbons in the caprock groundwater are not likely to threaten offsite human or ecological receptors.

5.5 CONCEPTUAL SITE MODEL

The Phase I RI evaluated potentially complete pathways for onsite and offsite receptors as a result of exposure to residual onsite contamination from the 1971 MOGAS release. The focus of the Phase II RI is to further evaluate potential offsite impacts from the 1971 MOGAS release. Therefore, the conceptual site model (CSM) and human health and ecological risk assessments (Sections 6 and 7) focus on complete exposure pathways for offsite receptors.

The CSM for the offsite study area, which is the focus of the Phase II RI risk assessment, identifies potentially complete exposure pathways for both current and future land uses of the area. Figure 5-15 presents the CSM for residual subsurface soil contamination from the 1971 MOGAS release and the CSM for other contaminant sources not related to the MOGAS release.

5.5.1 Current and Future Land Uses

The offsite study area is and has been used primarily for residential and agricultural purposes. Because the hydrology in the area provides ideal conditions for growing hydric farm crops, this current land use is expected to continue. It is anticipated that future land development will not include major construction activities (i.e., subsurface excavation); however, small-scale excavation (i.e., for installation of utility lines) is possible.

5.5.2 Contaminant Sources and Chemical Transport Mechanisms

Contaminant Sources. The current contaminant source of concern is residual onsite subsurface soil contamination from the 1971 MOGAS release. No floating product has been observed in more than 10 years; therefore, onsite subsurface soil contaminated with residual hydrocarbons, primarily BTEX compounds and light-end PAHs, represents the only current onsite source of caprock groundwater hydrocarbon contamination. These MOGAS-related compounds in onsite caprock groundwater are naturally attenuated through aerobic and anaerobic biodegradation (see Section 5.3). These naturally occurring processes have significantly reduced caprock groundwater BTEX concentrations and restricted the offsite migration of these compounds.

Concentrations of MOGAS-related constituents detected off site were very low (see Section 4). However, the Phase II RI sampling and analysis program identified other contaminants in the offsite area that are not likely to be related to the 1971 MOGAS release. COPCs detected in offsite surface media samples were primarily SVOCs (including phthalates, heavy-molecular-weight PAHs, and lead). Subsurface soil contains primarily the same COPCs as well as low concentrations of gasoline-range TPH. (Non-MOGAS related COPCs and the MOGAS-related COPCs detected at low-levels are identified in Section 6.) Surface water in the watercress fields and at the outfalls located between the bicycle path and Middle Loch contains heavy-molecular-weight PAHs, 2-nitrophenol, phthalates, and lead. Groundwater collected from offsite wells installed in the caprock water-bearing zone contains VOCs, SVOCs (e.g., PAHs, phthalates, and phenolics), and lead.

Comparison between COPCs identified for onsite media in the Phase I RI risk assessment and those identified for the offsite Phase II RI risk assessment suggest that multiple contaminant sources may be responsible for contamination detected in the offsite area. VOCs identified as COPCs in onsite surface soil (i.e., BTEX) are associated with the MOGAS release. Pesticides, PCBs, and lead were COPCs in onsite surface soil, but were not attributed to the MOGAS release. In contrast, none of the COPCs identified in onsite surface soil were detected in offsite surface soil. COPCs in offsite surface soil and sediment were primarily PAHs, most of which have heavy molecular weights and are not considered constituents of MOGAS. The other COPCs detected in offsite surface soil and sediment (e.g., phthalates, 2-butanone, acetone, and carbon disulfide) are also not likely to be related to the 1971 MOGAS release.

COPCs detected by Phase I RI onsite subsurface soil sampling (i.e., BTEX, 1,2-DCA, trichloroethene [TCE], phenolic compounds, and naphthalenes) are associated with the onsite MOGAS contaminant source. Many of these chemicals were also identified as COPCs in the Phase II RI offsite subsurface soil samples. However, like offsite surface soil and sediment, offsite subsurface soil also contained heavy-molecular-weight PAHs, phthalates, 2-butanone, acetone, and carbon disulfide.

COPCs identified in offsite surface water were also identified in offsite surface soil and sediment, with the exception of 2-nitrophenol, butylbenzylphthalate, and di-n-octylphthalate.

Contributing Sources			Transport Mechanism	Exposure Route		Current Land Use		Future Land Use			Rationale	
Pathway				Farm Worker	Resident	Farm Worker	Resident	Utility Worker				
Contaminant Source: Residual Onsite Subsurface Soil Contamination Associated with the 1971 MOGAS Release												
Ground-water	<div>Onsite Subsurface Soil Leaching Groundwater</div>	<div>Flow Movement</div>	<div>Ingestion of Domestic Groundwater Dermal Contact with Domestic Groundwater Inhalation of VOCs from Domestic Groundwater Ingestion of Agricultural Plants/ Animals (bio-uptake) Incidental Ingestion of Surface Water Dermal Contact with Surface Water Inhalation of VOCs from Surface Water Ingestion of Agricultural Plants/ Animals (bio-uptake) Incidental Ingestion of Surface Water Dermal Contact with Surface Water Inhalation of VOCs from Surface Water Ingestion of Fish/ Shellfish (bio-uptake)</div>	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Domestic water for these receptors is supplied by the confined basal aquifer. Caprock water is not potable and is not a potential future drinking water source.	
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	The pathway is complete for all receptors, but is considered insignificant because of tight, moist, silty clayey soils.
				Insignificant	Insignificant	Insignificant	Incomplete	Incomplete	Incomplete	Incomplete	Insignificant	Water used for growing agricultural plants is supplied by the confined basal aquifer. Caprock water is not potable and is not a potential future drinking water source.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	There is no evidence of discharge of the caprock water-bearing zone to surface water in the ofsite study area. The caprock groundwater is at least 2 feet below the bottom of the watercress field surface water.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Water used for growing agricultural plants is supplied by the confined basal aquifer. Caprock water is not potable and is not a potential future drinking water source.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Farm workers, residents, and future utility workers are assumed not to use Pearl Harbor Middle Loch for recreational purposes. Recreational use of the Middle Loch is discussed in Section 5.5.4.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	The potential effect of contaminant discharge to Pearl Harbor is the subject of a separate investigation, as discussed in Section 5.5.4.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	The basal aquifer hydraulic head is higher than caprock groundwater and, therefore, caprock groundwater contaminants cannot migrate downward to the confined basal aquifer.
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete
Contaminant Source: Offsite Soil and Sediment Contamination Not Associated with the 1971 MOGAS Release												
Air	<div>Offsite Surface Soil/Sediment</div>	<div>Wind-borne Particulates Volatilization</div>	<div>Inhalation of Fugitive Particulates Inhalation of VOCs</div>	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	The pathway is complete for farm workers and residents, but insignificant because of relatively low concentrations and high soil moisture content. The pathway is complete for utility workers, but is insignificant compared to direct contact.	
				Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant		
Soil/ Sediment	<div>Offsite Surface Soil/ Subsurface Soil/ Sediment (Watercress Fields)</div>	<div>Direct Contact</div>	<div>Incidental Ingestion of Soil/Sediment Dermal Contact with Soil/Sediment Ingestion of Agricultural Plants/Animals (bio-uptake)</div>	Complete	Complete	Complete	Complete	Complete	Complete	Complete	Residents may contact surface soil/sediment. Utility workers may contact surface soil/ sediment and subsurface soil.	
				Complete	Complete	Complete	Complete	Complete	Complete	Complete	Farm workers, residents, and utility workers may consume watercress grown at the watercress fields.	
				Complete	Complete	Complete	Complete	Complete	Complete	Complete	The pathway is complete for farm workers but is considered insignificant compared to direct contact. The pathway is insignificant for residents and future utility workers who are assumed not to be in frequent contact with surface water at the watercress fields.	
Surface Water	<div>Offsite Surface Soil/Sediment</div>	<div>Overland Flow to Watercress Fields Overland Flow to Pearl Harbor Middle Loch</div>	<div>Incidental Ingestion of Surface Water Dermal Contact with Surface Water Inhalation of VOCs from Surface Water Ingestion of Agricultural Plants/Animals (bio-uptake) Incidental Ingestion of Surface Water Dermal Contact with Surface Water Inhalation of VOCs from Surface Water Ingestion of Fish/Shellfish (bio-uptake)</div>	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Insignificant	Farm workers may contact surface water in the watercress fields. The pathway is insignificant for residents and future utility workers who are assumed not to be in frequent contact with surface water at the watercress fields.	
				Complete	Complete	Complete	Complete	Complete	Complete	Complete	The pathway is incomplete because VOCs were not detected in surface water.	
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Farm workers, residents, and future utility workers may consume watercress grown at the watercress farms.	
				Complete	Complete	Complete	Complete	Complete	Complete	Complete	Farm workers, residents, and future utility workers are assumed not to use Pearl Harbor Middle Loch for recreational purposes. Recreational use of the Middle Loch is discussed in Section 5.5.4.	
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	The potential effect of contaminant discharge to Pearl Harbor is the subject of a separate investigation, as discussed in Section 5.5.4.	
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete		
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete		
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete		
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete		
				Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete	Incomplete		

Figure 5-15
Conceptual Site Model
 Phase II RI, Ewa Junction Fuel Drumming Facility
 Pearl Harbor, Oahu, Hawaii

Transport Mechanisms. Contaminants detected in the offsite investigation area could migrate in the environment by the following mechanisms:

- *Air.* Air transport of chemicals detected in soil (i.e., transport via airborne particulates or as vapor phase of volatile chemicals) is considered insignificant at this site. Transport of nonvolatile COPCs by air is insignificant due to heavy vegetative cover in the contaminated area and the low contaminant concentrations detected in surface soil and sediment. Transport of VOCs is insignificant due to their relatively low concentrations in surface soil, sediment, and caprock groundwater underlying the offsite study area.
- *Leaching.* VOCs, PAHs, phthalates, phenolics, and lead were detected in offsite soil and sediment. PAHs are not expected to significantly leach from soil to groundwater or surface water due to their fate and transport properties (high affinity for soil particles and low solubility in water). However, the solubility and, therefore, mobility of PAHs can increase in the presence of phenolic compounds (which have been detected in all media sampled in the investigation area). Lead and VOCs are more readily leached from soil, and are expected to occur in the caprock groundwater.
- *Groundwater.* Caprock groundwater is encountered at approximately 8–12 feet bgs in the offsite area. There is no evidence that caprock groundwater discharges to fresh surface water in the offsite area (i.e., the watercress fields). However, caprock groundwater may discharge to the Middle Loch of Pearl Harbor below the low tide elevation. Contamination in Pearl Harbor is being investigated under a separate CLEAN investigation.
- *Artesian Wells.* Artesian wells that tap the deep basal aquifer underlying the offsite area provide irrigation water for the watercress fields. The confined basal aquifer also discharges to the surface at several springs east of the offsite investigation area (e.g., Waiawa Spring). The basal aquifer is hydrogeologically separate from the surficial caprock water-bearing zone: it is isolated from the caprock groundwater by a thick sequence of impermeable confining strata. The local hydraulic gradient also prevents caprock groundwater from entering the basal aquifer: the potentiometric surface of the confined basal aquifer is higher than that of the unconfined caprock water-bearing zone. There is no evidence of contamination in the artesian wells downgradient of the EJFDF.
- *Surface Water.* Erosion is the primary mechanism for transport of onsite soil contaminants to the offsite area. Surface water may transport contaminants sorbed to suspended soil particles or leached from surface soil by sheet wash. Contaminants are more likely to migrate with suspended soil particles, which could be transported to the watercress fields and the field drainage system. If contaminated surface soil particles were transported to the watercress fields via surface water runoff, the large volume of irrigation water supplied by the confined basal aquifer would dilute the small volume of surface runoff. Contaminated soil particles could be deposited as sediments in drainage ditches at points where flow velocity is low. Dissolved contaminants in the runoff could be transported to Middle Loch, where further dilution would occur during tidal flushing of the harbor.

5.5.3 Complete and Potentially Complete Exposure Pathways and Potential Receptors

Offsite exposure pathways and receptors are evaluated in this Phase II RI. Onsite exposure pathways and receptors were evaluated in the Phase I RI baseline risk assessment (Ogden 1996).

Human Exposure Pathways. Complete or potentially complete human exposure pathways for the offsite area are identified as follows (grouped by contaminant source):

- Onsite residual subsurface soil contaminant source associated with the 1971 MOGAS release
 - Intake of chemicals that have bioaccumulated in fish in Middle Loch
- Offsite contaminant sources not associated with the 1971 MOGAS release
 - Intake of chemicals via inhalation of fugitive dust from soil
 - Intake of gas-phase VOCs from soil via inhalation
 - Intake of chemicals in offsite surface soil or sediment in the watercress farm area via incidental ingestion and dermal absorption (surface soil and sediment are considered together because their intake could occur in the same manner)
 - Intake of chemicals in subsurface soil via incidental ingestion and dermal absorption
 - Intake of chemicals that have bioaccumulated in agricultural plants
 - Intake of chemicals in surface water in the watercress fields and surface water drainage areas via incidental ingestion and dermal absorption

Incomplete human exposure pathways in the offsite study area are identified as follows (grouped by contaminant source):

- Onsite residual subsurface soil contaminant source associated with the 1971 MOGAS release
 - Current and future exposure to contaminants in surface water in Pearl Harbor Middle Lock. Human receptors are assumed to not use the area for recreational purposes.
- Offsite contaminant sources not associated with the 1971 MOGAS release
 - Exposure to VOCs from surface water in the watercress fields. VOCs were not detected there.
 - Current exposure to contaminants in the caprock water-bearing zone. This zone is not a source of potable water. Domestic water is supplied by the deeper basal aquifer, which is hydrogeologically separate from the overlying caprock water-bearing zone; contaminants were not detected in artesian well water from the confined basal aquifer.
 - Future exposure to contaminants in offsite caprock groundwater. It is assumed that the caprock water-bearing zone will not be used as a water source in the future.

Human Receptors. Current and potential future human receptors associated with the offsite study area are farm workers and residents who may or may not work at the farms. In addition, although major construction is not expected, utility workers are potential future receptors if small-scale excavation (i.e., installation of utility lines) occurs. Recreational users of Middle Loch are potential receptors; however, they were not evaluated in the Phase II RI risk assessment, as discussed in Section 5.5.4.

Current and potential human receptors based on complete and significant exposure pathways for the offsite study area are identified as follows:

- Current and future farm workers and residents who may contact surface soil or sediment in the offsite area. Pathway: surface soil or sediment exposure (i.e., dermal absorption).
- Future utility workers during excavation activities (e.g., underground pipe removal or repair). Pathway: subsurface soil exposure (i.e., incidental ingestion and dermal absorption).

- Current and future farm workers who may contact surface water in the watercress fields. Pathway: the (potentially complete) surface water exposure (i.e., dermal absorption).
- Current and future farm workers, residents, and future utility workers who may consume agricultural plants grown at the watercress farms. Pathway: bioaccumulation.

Current and potential human receptors based on complete but insignificant exposure pathways are identified as follows (grouped by contaminant source). Rationale for considering these pathways as insignificant is presented in Figure 5-15.

- Onsite residual subsurface soil contaminant source associated with the 1971 MOGAS release
 - Current and future farm workers and residents, and future utility workers. Pathway: inhalation of VOCs from groundwater.
- Offsite contaminant sources not associated with the 1971 MOGAS release
 - Current and future farm workers and residents, and future utility workers. Pathway: inhalation of fugitive dust particulates and VOCs from soil or sediment.
 - Current and future residents, and future utility workers. Pathway: incidental ingestion and dermal absorption of surface water in the watercress fields.
 - Farm workers. Pathways: incidental ingestion and dermal absorption of surface soil or sediment, and incidental ingestion of surface water.

5.5.4 Recreational Use of Middle Loch

Exposure to contaminants in Middle Loch is considered an incomplete pathway for farm workers, residents, and utility workers because these receptors are assumed to not use Middle Loch for recreational purposes. Use of Middle Loch for recreational purposes is possible, but rare: the area is unsuitable for swimming and fishing is currently unlikely due to a ban on consuming fish from Pearl Harbor. The effects of fish consumption in the future are not addressed in the Phase II RI risk assessment; bioaccumulation of contaminants in fish in Middle Loch is being investigated under a separate effort (Pearl Harbor Sediment Study, Ogden Environmental and Energy Services Co., in progress).

Although Pearl Harbor Middle Loch is not suitable for recreational use, it was conservatively evaluated in the Phase I RI risk assessment (Ogden 1996). Risks to adults and children who swim in Middle Loch were estimated. COPCs were selected from chemicals detected in caprock groundwater, which was assumed to discharge to Middle Loch. Comparisons to EPA Region IX tap-water PRGs and to background concentrations (including laboratory contaminants) were primary considerations in selecting COPCs from the list of chemicals detected in the groundwater. Concentrations in Middle Loch were estimated by multiplying groundwater COPC concentrations by the dilution factor calculated for the Pearl Harbor estuarine environment.

Risks to adults and children swimming in Middle Loch estimated in the Phase I RI risk assessment (Ogden 1996) are presented in Table 5-7.

Table 5-7: Risks to Adults and Children Swimming in Middle Loch

Receptor/Pathway	Cancer Risk		Hazard Index	
	Average	RME	Average	RME
Adult				
Ingestion of surface water	5E-13	1E-09	7E-07	2E-06
Dermal contact with surface water	5E-12	6E-08	5E-07	3E-04
Child				
Ingestion of surface water	2E-13	2E-10	2E-08	4E-06
Dermal contact with surface water	6E-13	4E-09	3E-07	8E-05

Results of Phase I and Phase II RI groundwater sampling indicate that maximum VOC concentrations in the caprock water-bearing zone continue to decrease due to natural attenuation. Consequently, it is assumed that risks to potential future recreational users estimated for the Phase I RI would not be exceeded.

Ecological Receptors. During the ecological reconnaissance, a variety of birds and other animals were observed using the watercress farm area. A flock of seven Hawaiian black-necked stilts (*Himantopus mexicanus knudseni*), an endangered species, were observed feeding on aquatic organisms at the adjacent Nakatani watercress farm. Cattle egrets are commonly observed feeding in the offsite area. Both species are known to breed at the nearby Waiawa Unit of the Pearl Harbor National Wildlife Refuge. Surface water and groundwater from the offsite area may discharge to Middle Loch, where aquatic receptors could be exposed. The potential effect of contaminant discharge to Pearl Harbor is the subject of a separate investigation.

The following are complete or potentially complete ecological exposure pathways for the offsite study area:

- Uptake of chemicals in surface water by fish and other aquatic organisms
- Uptake of chemicals in sediment by benthic invertebrates
- Ingestion of chemicals in sediment by black-necked stilts feeding in watercress fields
- Ingestion of chemicals in contaminated food species by black-necked stilts feeding in the watercress fields (food chain exposure)
- Ingestion of chemicals in soil by representative terrestrial species
- Ingestion of chemicals in contaminated food species by representative species feeding in the upland portion of the offsite area
- Root uptake of chemicals in soil by terrestrial plants
- Root uptake of chemicals in sediment by hydric plants, such as watercress

Surface water and caprock groundwater ultimately discharge to Middle Loch; therefore, these pathways are also potentially complete for the Pearl Harbor aquatic community. The Navy's Pearl Harbor Sediment Study is evaluating the Pearl Harbor aquatic and benthic communities (Ogden, in-progress). Potential risks to biological resources in the harbor are qualitatively discussed based on analytical results from surface water and sediment samples collected at two outfalls that discharge runoff from the offsite area to Middle Loch (see Section 7).

6. HUMAN HEALTH RISK ASSESSMENT

The Phase II RI human health risk assessment estimated risks to farm workers, residents, and utility workers associated with exposure to COPCs detected in the offsite investigation area. Phase II RI findings indicate that the risk drivers detected off site are not related to the EJFDF MOGAS release. Results of the risk assessment indicate that, with one exception, offsite contaminants do not pose unacceptable risks to human receptors. A cumulative risk of $1\text{E}-03$ was calculated for dermal contact by farm workers with HMW SVOCs such as benzo(a)pyrene in surface water. The heavy SVOCs were not detected in onsite or offsite caprock groundwater, and are not likely to be related to the 1971 MOGAS release. Due to their physicochemical properties, the detected SVOCs are expected to be largely adsorbed to suspended soil particles, which would significantly limit their bioavailability. This assumption is supported by analytical data from filtered samples collected from the artesian wells that irrigate the watercress farms, and by the low aqueous solubility and high sediment-partitioning values reported in the literature for these SVOC compounds. In addition, the calculated risk to farm workers is the result of SVOC concentrations detected in a single surface water sample, which was collected from a drainage channel, not in the watercress patches themselves. The risk to farm workers who contact surface water is therefore likely to be overestimated.

For the Phase I RI, human health risks associated with the 1971 MOGAS release were estimated by a baseline HRA (Ogden 1996). Four receptors were evaluated:

- Current onsite visitors
- Future onsite residents
- Current or future offsite residents
- Current or future offsite farm workers

Six potentially complete pathways were evaluated for the Phase I RI:

- Ingestion of and dermal contact with surface soil
- Ingestion of and dermal contact with Pearl Harbor surface water while swimming
- Dermal contact with watercress patch water and inhalation of VOCs volatilized from the water

The HRA for the Phase I RI assumed that caprock groundwater discharges into Pearl Harbor and the watercress patches (Ogden 1996).

COPCs identified in the Phase I RI HRA, which evaluated the area surrounding the 1971 MOGAS release, are listed in Table 6-1:

Table 6-1: COPCs Identified in the Phase I RI Health Risk Assessment

COPCs in Soil	COPCs in Underlying Caprock Water-Bearing Zone
Aroclor 1260	BEHP
DDE	BTEX
DDT	Chloromethane
Ethylbenzene	1,2-DCA
Lead	Hexane
Toluene	2-Methylnaphthalene
Xylenes	Naphthalene
	TCE

Source: Ogden (1996).

Cumulative risk to potential future onsite residents was the highest estimated in the Phase I RI HRA. The risk calculated for these receptors was $4\text{E}-06$. For all other receptors, the cumulative RME risks were less than $1\text{E}-06$ (e.g., risk to future offsite farm workers as a result of dermal contact with water in the watercress fields and inhalation of VOCs volatilizing from the pond water was estimated to be $8\text{E}-09$). All hazard indexes (HIs) were less than 1.

The purpose of the current risk assessment is to supplement the Phase I risk assessment with Phase II RI data. This risk assessment considers offsite contamination from two different contaminant sources:

- Residual onsite subsurface soil contamination from the MOGAS release
- Offsite contaminant sources not related to the MOGAS release

As indicated in the CSM (Section 5.5), the contaminants detected in the offsite investigation area are not likely to be related to the MOGAS release.

6.1 METHODOLOGY FOR RISK EVALUATION

The HRA was completed using the preliminary risk evaluation (PRE) approach, developed with guidance from the following:

- Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual (Part A) (EPA 1989a)
- Risk Assessment Guidance for Superfund, Volume 1: Human Health Evaluation Manual Supplemental Guidance, Standard Default Exposure Factors (EPA 1991)
- Communications between EPA Region IX Toxicologist Dr. Daniel Stralka and the CLEAN I contractor (Stralka 1995)

A PRE compares exposure point concentrations (EPCs) to EPA Region IX PRGs, and is appropriate when the following criteria are met:

- The complete or potentially complete exposure pathways of concern at a site are identical to those used to develop the PRGs.
- Pathway-specific exposure parameters for receptors at a site are expected to be similar to the EPA Region IX default assumptions used to develop the PRGs.

PRGs do not consider all exposure pathways (e.g., exposure to indoor air from soil gas; ingestion or dermal absorption of chemicals while swimming, wading, or bathing; ingestion of contaminated fish, meat, dairy products, fruit, or vegetables; and impact to groundwater). PRGs are not intended as stand-alone decision-making tools or as a substitute for EPA guidance when preparing baseline risk assessments. When using PRGs to screen for COPCs and provide preliminary cleanup goals, residential soil PRGs should be used to reflect maximum potential beneficial uses for the site.

A PRE typically consists of a screening PRE and a site-specific PRE. As a conservative approach, the screening PRE consists of comparison of site EPCs with residential PRGs. If risk is found acceptable, the risk evaluation is considered complete. If risk is found unacceptable, site EPCs are compared with industrial PRGs (if industrial exposure pathways have been identified). If industrial risk is found unacceptable, or exposure pathways different from those used to develop PRGs have been identified, a site-specific PRE is completed.

This risk evaluation includes a screening PRE and a site-specific PRE; the methodologies for both PREs are discussed below.

6.1.1 Screening PRE Methodology

The screening PRE includes the following steps:

- Develop a CSM.
- Identify relevant data sets.
- Select COPCs.
- Estimate EPCs.
- Calculate screening cumulative health risks.
- Evaluate results.

Conceptual Site Model. The CSM (Section 5.5) identified complete and potentially complete exposure pathways for current and future land uses.

The CSM identified farm workers and residents as current and future receptors, and utility workers as potential future receptors. These receptors could contact contaminated offsite soil or sediment. Farm workers could also contact contaminated offsite surface water in the watercress fields. As discussed in Section 5.5.2, air transport and exposure to offsite contaminants is considered insignificant due to the tight, moist soils, significant vegetative cover, and relatively low contaminant concentrations. Complete and potentially complete exposure pathways identified in Section 5.5.3 are further evaluated below.

For PRGs to be relevant in the risk assessment, exposure pathways and exposure parameters in the CSM should be similar to those used to develop the PRGs used for comparison. The residential exposure pathways and exposure parameters identified in the CSM are the same as those used to develop residential PRGs. However, comparison to industrial PRGs is not appropriate for farm workers or utility workers because complete exposure pathways identified for these receptors in the CSM are not similar to those used to develop PRGs; these pathways will be addressed in the site-specific PRE, and include the following:

- Dermal contact with contaminants in surface water by current and future farm workers
- Ingestion of watercress by all identified receptors (i.e., farm workers, residents, and utility workers)
- Ingestion of and dermal contact with contaminants in offsite soil (i.e., surface soil, sediment, and subsurface soil) by future utility workers

Relevant Data Sets. Soil, sediment, and surface water data were evaluated for the screening PRE. Data were validated in accordance with the most currently available version of the U.S. Navy PACDIV *Project Procedures Manual* (for round one samples, DON 1996; for round-two samples, DON 1998). Ten percent of the analytical data were validated according to U.S. Navy Pacific Division (PACDIV) Level D data validation criteria; 90 percent of the data were validated according to PACDIV Level C criteria. Data assigned an "R" qualifier (data rejected) were eliminated from the database and were not used for the screening PRE. TPH analytical data were not included in the screening PRE because PRGs do not exist for these constituents; however, the most toxic components, e.g., BTEX compounds and PAHs, were included.

Soil data were segregated into surface soil data (i.e., 0–0.5 ft bgs) and subsurface soil data (i.e., 0.5–32 feet bgs). Surface soil data are from five offsite surface soil samples and nine sediment samples (including one duplicate sample) collected from the watercress patches and offsite drainage channels. Sediment data were included with surface soil data because human receptors could ingest and contact sediments in the same manner as surface soil. Subsurface soil data are from 43 soil samples (including four duplicate samples) collected in the offsite investigation area at various depths between 0.5 and 32 feet bgs.

Surface water data consist of nine samples (including one duplicate) collected at the watercress patches and drainage areas. Two sediment samples (D-01 and D-02) and two surface water samples (W-01 and W-02) were collected at outfall areas downgradient of the offsite investigation area, at the shoreline of Pearl Harbor Middle Loch. These two sampling locations were not used for the screening PRE because they were not considered representative of the offsite investigation area. In addition to the offsite investigation area, other upgradient areas drain to these outfalls. The shoreline area is also influenced by tidal waters of Pearl Harbor Middle Loch.

Chemicals of Potential Concern. Any chemical detected in the offsite soil, sediment, or surface water was considered a COPC and was included in the screening PRE. Chemicals included in the PRE are listed in Table 6-2. The table lists chemicals that were detected in each medium at least once, and indicates those chemicals that are not evaluated quantitatively because they lack PRGs.

Table 6-2: Chemicals of Potential Concern Included in the Human Health PRE

COPCs in Surface Soil or Sediment	COPCs in Subsurface Soil	COPCs in Surface Water
VOCs		
2-Butanone Acetone Carbon disulfide	Acetone 2-Butanone Carbon disulfide 1,2-DCA Ethylbenzene 1,2,4-TMB 1,3,5-TMB Xylenes, total	none
SVOCs		
Anthracene Benzo(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(k)fluoranthene BEHP 4-Bromophenyl-phenylether ^a Chrysene Dibenzo(a,h)anthracene Diethyl phthalate Fluoranthene Indeno(1,2,3-c,d)pyrene Phenanthrene Phenol Pyrene	Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene BEHP Di-n-butylphthalate Diethylphthalate Hexachlorobenzene 2-Methylnaphthalene Naphthalene 2-Nitrophenol Phenol Pyrene	Benzo(a)anthracene Benzo(a)pyrene Benzo(b)fluoranthene Benzo(g,h,i)perylene Benzo(k)fluoranthene BEHP Butylbenzylphthalate Chrysene Di-n-octylphthalate Dibenzo(a,h)anthracene Fluoranthene Indeno(1,2,3-c,d)pyrene 2-Nitrophenol Phenanthrene Pyrene
Inorganics		
Lead	Lead	Lead

^a A PRG is not available for comparison against EPCs; therefore, this chemical is not considered in the PRE.

Exposure Point Concentrations. Both maximum EPCs and RME EPCs were estimated. The distribution of analytical concentrations for each chemical was evaluated using the Shapiro-Wilk test (Gilbert 1987). Distribution results are presented in Appendix N, Table N-2.

The 95 percent upper confidence limit (UCL) of the arithmetic mean will represent the RME EPC. Non-detected values were represented by one-half the detection limit for quantification of the 95 percent UCL concentration.

The following formula was used to calculate the 95 percent UCL of the arithmetic mean concentration for normally distributed data (EPA 1992):

$$95\% UCL = \bar{x} + (t_{0.95, n-1}) \left(\frac{s}{\sqrt{n}} \right)$$

Where:

- \bar{x} = arithmetic mean concentration
- $t_{0.95, n-1}$ = 95% t-distribution value for n-1 degrees of freedom
- s = standard deviation
- n = number of samples

The following equation was used to calculate the 95 percent UCL of the arithmetic mean for lognormal distribution:

$$95\% UCL = e^{\left[\bar{x} + 0.5s^2 + \frac{3H}{\sqrt{n-1}} \right]}$$

Where:

- e = base of natural log, approximately equal to 2.718
- \bar{x} = arithmetic mean of the natural logarithms of the analyte concentrations
- s = standard deviation of the natural logarithms of the analyte concentrations
- H = H-statistic (American Mathematical Society 1975)
- n = number of contaminant samples

If the 95 percent UCL concentration exceeded the maximum concentration for a specific chemical data set, the maximum concentration was used as the RME EPC.

Cumulative Health Risks. To evaluate risk to residents from exposure to COPCs in soil or sediment through soil and air exposure pathways, maximum EPCs and RME EPCs were compared to residential soil PRGs. Soil PRGs represent the soil concentrations from the assumed soil and air pathways below which no significant health effects are likely to occur. They correspond to fixed levels of risk (i.e., a cancer risk of 1E-06 or a noncancer hazard quotient of 1). The following soil and air pathways were used to develop residential soil PRGs:

- Inhalation of contaminated, fugitive dust from soil
- Inhalation of VOCs from soil
- Incidental ingestion of chemicals in soil
- Dermal contact with chemicals in soil

Children from 0 to 6 years old were selected as receptors for calculating noncarcinogenic PRGs. Individuals from 0 to 30 years old (i.e., 30-year residents) were selected as receptors for calculating carcinogenic PRGs. Therefore, both adult and child exposures are addressed through use of the residential soil PRGs.

Some PRGs are listed as a "sat" concentration (PRG_{sat}). These correspond to a saturation concentration in soil where the absorptive limits of the soil particles and the available soil moisture have been reached. If a health-based PRG exceeds the PRG_{sat} , the PRG_{sat} was listed and used for comparison. Some PRGs are listed as a "max" concentration (PRG_{max}). PRG_{max} concentrations may be established for inorganic or SVOCs with relatively low toxicity. PRG_{max} concentrations are non-health-based ceiling limit concentrations, and are fixed at $1E+05$ mg/kg. If a health-based PRG was unavailable for comparison, but a PRG_{max} was available, the PRG_{max} was used for contaminant concentration comparison.

Excess cancer risk can be estimated from an EPC and a carcinogenic PRG with the following formula:

$$Excess\ Cancer\ Risk = TR \times \frac{EPC_i}{PRG_i}$$

Where:

- TR = the target lifetime cancer risk of $1E-06$
 EPC_i = maximum EPC or RME EPC of $COPC_i$ detected in soil (mg/kg)
 PRG_i = PRG for $COPC_i$ in soil (mg/kg), based on carcinogenic effects

A hazard quotient (HQ) can be estimated from an EPC and a noncarcinogenic PRG with the following formula:

$$HQ = THQ \times \frac{EPC_i}{PRG_i}$$

Where:

- THQ = the target hazard quotient (HQ) of 1

The cumulative residential excess cancer risk is also estimated for each site. The cumulative excess cancer risk for exposure to multiple COPCs is estimated with the following equation:

$$Cumulative\ Excess\ Cancer\ Risk = \sum \left[TR \times \frac{EPC_i}{PRG_i} \right]$$

The cumulative noncarcinogenic HI for exposure to multiple COPCs is estimated as follows:

$$\text{Cumulative Noncarcinogenic HI} = \sum \left[\text{THI} \times \frac{\text{EPC}_i}{\text{PRG}_i} \right]$$

Where:

THI = the target HI of 1

Excess risks calculated by comparing the EPC to PRG_{sat} or PRG_{max} values were not included in the cumulative excess cancer risk or the cumulative HI. Instead, comparison results were evaluated qualitatively.

Evaluating Results. If maximum EPCs and RME EPCs are less than residential soil PRGs, cumulative excess cancer risk is less than $1\text{E-}06$, and the HI is less than 1, then no further action is recommended for the site.

As stated previously, soil concentrations are compared to industrial PRGs only if any of the following occur when comparing to residential soil PRGs:

- The cumulative RME excess cancer risk exceeds $1\text{E-}06$
- The cumulative HI exceeds 1
- The lead EPC in soil exceeds the residential PRG of 400 mg/kg

As discussed in Section 6.2, results for the above criteria were not exceeded for offsite soil or sediment contaminant concentration comparisons to residential soil PRGs. Therefore, it was not necessary to compare soil concentrations to industrial PRGs. However, a site-specific PRE was completed for exposure pathways different from those used to develop PRGs.

6.1.2 Site-Specific PRE Methodology

The site-specific PRE estimated exposure and risk associated with four exposure pathways:

- Dermal contact with surface water in the watercress fields by farm workers
- Ingestion of contaminated watercress by all identified receptors, i.e., farm workers, residents (adult and child), and utility workers
- Incidental ingestion of soil (i.e., surface soil, sediment, and subsurface soil) by utility workers
- Dermal contact with soil (i.e., surface soil, sediment, and subsurface soil) by utility workers

A screening PRE could not be completed for these pathways because they differ from the pathways used to develop PRGs; therefore, a site-specific PRE was necessary to assess risks associated with these pathways.

The site-specific PRE included the following four tasks:

- Identification of COPCs
- Exposure assessment
- Toxicity assessment
- Risk characterization

6.1.2.1 IDENTIFICATION OF COPCS

All chemicals detected in at least one offsite sample were identified as COPCs. These COPCs are listed in Table 6-2.

6.1.2.2 EXPOSURE ASSESSMENT

Exposure is quantified for the following:

- Absorbed chronic dose through dermal absorption of COPCs in surface water in the watercress fields is estimated for the farm workers.
- Intake is estimated for ingestion of watercress by all identified receptors, including farm workers, residents (adult and child), and utility workers.
- Subchronic daily intake is estimated for the future utility workers through incidental ingestion of chemicals in surface and subsurface soil.
- Absorbed subchronic dose is estimated for future utility workers through dermal absorption of chemicals in surface and subsurface soil.

The COPC concentration used to estimate intake is the RME EPC, which is the lesser of the 95 percent UCL of the arithmetic mean concentration and the maximum concentration. Statistics for analytical data are presented in Appendix N, Table N-1. The models and exposure factors used to estimate exposure are presented in Equation 6-1 through Equation 6-4. The model and exposure factors presented in Equation 6-1 for the farm workers represent an adult worker scenario, based on field observations of the age composition of that group of workers as well as the legal prohibitions concerning child labor. The factors presented in Equation 6-2 for ingestion of watercress by residents address both adult and child exposures. This intake is applicable to farm workers and utility workers as well, under the assumption that they also are local residents who may potentially consume the contaminated watercress.

Equation 6-1: Model for Estimating Absorbed Dose for Farm Workers, Dermal Absorption of Chemicals in Surface Water at Watercress Fields, Current and Future Exposure and Land Use

$$\text{Absorbed Chronic Dose (mg/kg-day)} = \frac{CW \times CF \times SA \times PC \times ET \times EF \times ED}{BW \times AT}$$

Where:

CW	= contaminant concentration in surface water (mg/L)
CF	= conversion factor (1 liter/1,000 cm ³)
SA	= skin surface area available for contact (cm ²)
PC	= chemical-specific dermal permeability constant (cm/hr)
ET	= exposure time (hours/day)
EF	= exposure frequency (days/year)
ED	= exposure duration (years)
BW	= body weight (kg)
AT	= averaging time (period over which exposure is averaged, in days)

Assumptions:

- Contaminant concentration in surface water (CW) is the RME EPC for samples taken from surface water at the watercress fields. Data are presented in Appendix N.
- Mean exposed skin surface area (SA) of a farm worker is 2,100 cm² (hands and forearms) (site-specific estimate and EPA 1997e). All field workers were observed to wear knee-high boots.
- Chemical-specific dermal permeability constants (PCs) were obtained from EPA (1997e).
- Exposure time (ET) is 8 hours/day (site-specific estimate).
- Exposure frequency (EF) is 250 days/year, or 5 days/week for 50 weeks/year (EPA 1991).
- Exposure duration (ED) for a farm worker is 25 years (EPA 1991).
- Body weight (BW) of a farm worker is 71.8 kg (EPA 1997b).

Averaging time (AT) is 25 years × 365 days/year for intake of a chemical when considering noncarcinogenic effects, and 70 years × 365 days/year for a chemical when considering carcinogenic effects.

Equation 6-2: Model for Estimating Intake for Residents, Ingestion of Contaminated Watercress, Current and Future Exposure and Land Use

$$\text{Intake (mg/kg - day)} = \frac{CFd \times I\text{Radj} \times FI \times EF}{AT}$$

Where:

CFd	= contaminant concentration in food (mg/kg)
IRadj	= age-adjusted ingestion rate (kg-year/kg-day)
FI	= fraction ingested from contaminated source (unitless)
EF	= exposure frequency (days/year)
AT	= averaging time (period over which exposure is averaged, in days)

Assumptions:

- Contaminant concentration in food (CFd) is based on soil concentration and plant: soil accumulation factors or deposition factors. Data are presented in Appendix N.
- Age-adjusted ingestion rate (IRadj) is 1.07E-05 kg-year/kg-day (see derivation below).
- Fraction ingested (FI) from the contaminated source is 1.0 (100%).
- Exposure frequency (EF) for a resident is 350 days/year (site-specific estimate).
- Averaging time (AT) is 30 years × 365 days/year for intake of a chemical when considering noncarcinogenic effects, and 70 years × 365 days/year for a chemical when considering carcinogenic effects.

Derivation of age-adjusted intake rate:

$$I\text{Radj (kg - yr / kg - day)} = \frac{I\text{Rc} \times E\text{Dc}}{B\text{Wc}} + \frac{I\text{Ra} \times (E\text{Dr} - E\text{Dc})}{B\text{Wa}}$$

Where:

I Rc	= ingestion rate—child (kg/day)
I Ra	= ingestion rate—adult (kg/day)
E Dc	= exposure duration—child (years)
E Dr	= exposure duration—resident (years)
B Wc	= body weight—child (kg)
B Wa	= body weight—adult (kg)

Assumptions:

- Ingestion rate for a child (I Rc) is 5.33E-06 kg/day; for an adult (I Ra) is 2.55E-05 kg/day (EPA 1997c, Table 9-13).
 - Exposure duration for a child (E Dc) is 6 years and for a resident (E Dr) is 30 years (EPA 1991).
 - Body weight of a child resident (B Wc) is 15 kg (EPA 1991) and of an adult resident (B Wa) is 71.8 kg (EPA 1997b).
-

Equation 6-3: Model for Estimating Intake for Utility Workers, Incidental Ingestion of Chemicals in Soil, Future Exposure and Land Use

$$\text{Subchronic Daily Intake (mg / kg - day)} = \frac{CS \times CF \times IR \times FI \times EF \times ED}{BW \times AT}$$

Where:

- CS = contaminant concentration in soil (mg/kg)
- CF = conversion factor (10^{-6} kg/mg)
- IR = ingestion rate (kg/meal)
- FI = fraction ingested from contaminated source (unitless)
- EF = exposure frequency (meals/year)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging time (period over which exposure is averaged, in days)

Assumptions:

- Contaminant concentration in soil (CS) is the lesser of the 95% UCL of the arithmetic mean or the maximum concentration. Data are presented in Appendix N.
 - Soil ingestion rate (IR) for a construction worker is 480 mg/day is used (EPA 1991).
 - Fraction ingested (FI) from the contaminated source is 1.0 (100%).
 - Exposure frequency (EF) for a construction worker is 250 days/year, or 5 days/week for 50 weeks/year (EPA 1991).
 - Exposure duration (ED) for a utility worker is 5 days (site-specific estimate).
 - Body weight of a utility worker is 71.8 kg (EPA 1997b).
 - Averaging time (AT) is (5 days \times 365 days/year) \times 365 days/year for noncarcinogenic effects, and 70 years \times 365 days/year for carcinogenic effects.
-

Equation 6-4: Model for Estimating Intake for Utility Workers, Dermal Absorption of Chemicals in Soil, Future Exposure and Land Use

$$\text{Absorbed Subchronic Dose (mg/kg-day)} = \frac{CS \times CF \times SA \times AF \times ABS \times ED}{BW \times AT}$$

Where:

- CS = contaminant concentration in soil (mg/kg)
- CF = conversion factor (10^{-6} kg/mg)
- SA = skin surface area available for contact (cm^2/event)
- AF = soil-to-skin adherence factor (mg/cm^2 skin)
- ABS = absorption factor (unitless)
- ED = exposure duration (years)
- BW = body weight (kg)
- AT = averaging time (period over which exposure is averaged, in days)

Assumptions:

- Contaminant concentration in soil (CS) is the lesser of the 95% UCL of the arithmetic mean or the maximum concentration. Data are presented in Appendix N.
- Exposed mean skin surface area (SA) is $5,700 \text{ cm}^2/\text{event}$ (head, hands, forearms, and lower legs) (EPA 1997e, Table 5).
- Soil-to-skin adherence factor (AF) is $0.082 \text{ mg}/\text{cm}^2$ (irrigation installers; EPA 1997e, Table 6).
- Absorption factor (ABS) is 0.1 (10%) for VOCs and SVOCs (EPA 1997e, Table 4).
- Exposure duration (ED) for a utility worker is 5 days (site-specific estimate).
- Body weight of a utility worker is 71.8 kg (EPA 1997b).
- Averaging time (AT) is $(5 \text{ days} \div 365 \text{ days/year}) \times 365 \text{ days/year}$ for noncarcinogenic effects, and $70 \text{ years} \times 365 \text{ days/year}$ for carcinogenic effects.

6.1.2.3 TOXICITY ASSESSMENT

Carcinogenic and noncarcinogenic toxicity values are derived as described below.

Carcinogenic Toxicity Values. In the first step of a carcinogenic toxicity assessment, the EPA evaluates human and animal studies to determine the weight-of-evidence classification for carcinogenicity. The EPA adjusts the weight-of-evidence classification upward or downward on the basis of other supporting carcinogenic evidence, such as metabolic and other pharmacokinetic studies, cell cultures or microorganism studies, or structure-activity studies. Table 6-3 presents the EPA weight-of-evidence classification system for carcinogenicity.

Table 6-3: EPA Weight-of-Evidence Classification System for Carcinogenicity

Class	Description
A	Human carcinogen
B	Probable human carcinogen B ₁ : Limited human data are available. B ₂ : Sufficient evidence in animals and inadequate or no evidence in humans.
C	Possible human carcinogen
D	Not classifiable as to human carcinogenicity
E	Evidence of noncarcinogenicity for humans

In the second step of a toxicity assessment, the EPA assigns a toxicity value to a chemical that quantitatively defines the relationships between dose and response. This toxicity value is called the slope factor. The EPA typically calculates slope factors for potential carcinogens with weight-of-evidence classifications of A, B₁, and B₂. Slope factors for chemicals in Class C are estimated on a case-by-case basis.

For carcinogens, the EPA assumes that any level of exposure to a chemical with carcinogenic effects poses a finite probability of generating a carcinogenic response. Consequently, in evaluating cancer risks, a carcinogenic effect threshold cannot be estimated.

The slope factor is an upper-bound estimate of the probability of a response per unit intake of a chemical over a lifetime (i.e., risk per unit dose or risk per mg/kg per day). The EPA uses mathematical models and procedures to extrapolate from carcinogenic responses observed at high doses to responses expected at low doses. After the data are fit to the appropriate model, the upper 95th percent confidence limit of the slope of the resulting dose-response curve is calculated. This value, the slope factor, is an upper 95th percent confidence limit of the probability of a response per unit intake of a chemical over a lifetime.

All slope factors used in the site-specific PRE were obtained from the EPA's primary source of toxicity values: the Integrated Risk Information System (IRIS) database (EPA 1999a). These slope factors have been verified by the EPA Carcinogen Risk Assessment Verification Endeavor (CRAVE) work group. Table 6-4 presents the following carcinogenic toxicity data for COPCs evaluated in the site-specific PRE: the oral slope factor, the weight-of-evidence classification, the type of cancer, and the source of the carcinogenic toxicity data.

For PAHs, an oral slope factor is available only for benzo(a)pyrene. Therefore, this compound was used as a surrogate for all other PAH COPCs that are classified as B₂ carcinogens: benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-c,d)pyrene. Because naphthalene has a weight-of-evidence classification of C (possible human carcinogen; see Table 6-3), the slope factor for benzo(a)pyrene was not applied as a surrogate for naphthalene.

The EPA has proposed the use of relative potency factors (RPFs) for assessment of risk from oral exposure to potentially carcinogenic PAHs. The RPFs give an estimated order of magnitude potency compared to benzo(a)pyrene; an RPF has been assigned to the seven PAHs that are classified as B₂ carcinogens. The notes at the bottom of Table 6-4 list the RPFs that have been assigned to potentially carcinogenic PAHs (EPA 1993a). The slope factors for the potentially carcinogenic PAHs presented in the table have been modified using the appropriate RPFs.

Table 6-4: Toxicity Values: Potential Carcinogenic Effects (Oral)

Chemical	Slope Factor (mg/kg-day) ⁻¹	Weight-of- Evidence Classification ^a	Type of Cancer
Benzo(a)anthracene	7.3E-01 ^b	B ₂ ^c	Liver and lung (mouse)
Benzo(a)pyrene	7.3E+00 ^c	B ₂	Forestomach, squamous cell papillomas, and carcinomas (mouse)
Benzo(b)fluoranthene	7.3E-01 ^b	B ₂ ^c	Lung, thorax, liver, skin (rat, mouse)
Benzo(k)fluoranthene	7.3E-02 ^b	B ₂ ^c	Lung, thorax (rat), liver, and lung (mouse)
BEHP	1.4E-02 ^c	B ₂	Hepatocellular carcinoma and adenoma (male mouse)
Butylbenzylphthalate	—	C ^c	Mononuclear cell leukemia (female rats)

Chemical	Slope Factor (mg/kg-day) ⁻¹	Weight-of- Evidence Classification ^a	Type of Cancer
Carbon disulfide	—	—	This substance has not undergone a complete evaluation and determination under EPA's IRIS program for evidence of human carcinogenic potential. ^c
Chrysene	7.3E-03 ^b	B ₂ ^c	Liver, lung tumors (mouse)
Dibenzo(a,h)anthracene	7.3E+00 ^b	B ₂ ^c	Lung, skin (mouse)
1,2-DCA	9.1E-02 ^c	B ₂	Hemangiosarcomas (male rat)
Hexachlorobenzene	1.6E+00 ^c	B ₂	Hepatocellular carcinomas (female rat)
Indeno(1,2,3-c,d)pyrene	7.3E-01 ^b	B ₂ ^c	Lung, thorax, skin (rat, mouse)
Lead	—	B ₂ ^c	Kidney (rat, mouse)
Naphthalene	—	C ^c	Inadequate data of carcinogenicity (humans); limited evidence of carcinogenicity (animals)

mg/kg-day = milligram per kilogram per day
 — = no data

The following are PAH relative potency factors (RPFs):

PAH	RPF
Benzo(a)anthracene	0.1
Benzo(a)pyrene	1.0
Benzo(b)fluoranthene	0.1
Benzo(k)fluoranthene	0.01
Chrysene	0.001
Dibenzo(a,h)anthracene	1.0
Indeno(1,2,3-c,d)pyrene	0.1

^a See Table 6-3 for definitions.

^b Value was obtained by multiplying the oral slope factor for benzo(a)pyrene by a chemical-specific RPF (EPA 1993a).

^c Retrieved from IRIS database (EPA 1999a).

Noncarcinogenic Toxicity Values. A reference dose (RfD) is the toxicity value most often used to evaluate noncarcinogenic effects resulting from exposure to contaminants. A chronic RfD is defined as an estimate (with uncertainty spanning an order of magnitude or greater) of a daily exposure level for the human population, including sensitive subpopulations, that is unlikely to pose an appreciable risk of deleterious effects during a lifetime. Chronic RfDs are generally used to evaluate potential noncarcinogenic effects for an exposure period of 7 years to a lifetime (i.e., 70 years). For this risk assessment, chronic RfDs were used to evaluate potential noncarcinogenic effects for current or future farm workers. Subchronic RfDs are used for receptor exposure of 2 weeks to 7 years; subchronic RfDs were used to evaluate potential noncarcinogenic effects for future utility workers.

For the oral RfD, the EPA examines all available animal and human toxicological studies for a chemical following exposure by the oral route. If adequate human data are available, this information is used. If adequate human data are not available, animal study data are used. If only animal study data are available, the EPA selects the study on the most sensitive animal species as the critical study for the basis of the RfD. The most sensitive species is that species showing a toxic effect at the lowest administered dose.

Once the critical study and toxic effect have been selected, the EPA identifies the no-observed-adverse-effect level (NOAEL) for the study. The NOAEL is the exposure level that represents the highest level tested at which no adverse effects, including the critical effect, were demonstrated. In some studies, only a lowest-observed-adverse-effect level (LOAEL) is available. The EPA may use the LOAEL to determine the RfD, but this increases the uncertainty in the RfD value.

The RfD is calculated from the NOAEL (or LOAEL if a NOAEL is unavailable) by application of uncertainty factors (UFs) and a modifying factor (MF). UFs usually consist of multiples of 10. Each UF represents a specific area of uncertainty that the EPA establishes in extrapolation from available data. The following UFs are applied to the extrapolated data:

- UF of 10 to account for variation in the general human population. This UF is intended to protect sensitive subpopulations, such as the elderly or children.
- UF of 10 to account for extrapolation from animal studies to human studies
- UF of 10 to account for a NOAEL that is derived from a subchronic rather than a chronic study
- UF of 10 to account for the use of a LOAEL rather than a NOAEL

In addition to UFs, an MF ranging from greater than 0 to 10 is used to reflect a qualitative professional assessment of additional uncertainties in the critical study selected and in the entire database applicable to the critical study.

The EPA calculates an RfD by dividing the NOAEL (or LOAEL if a NOAEL is unavailable) by the products of all UFs and the MF. RfDs are expressed in units of mg/kg per day. Most oral RfDs are based on administered doses rather than absorbed doses.

The first source for RfDs used in the site-specific PRE was the EPA's (1999a) IRIS database. If RfDs were unavailable in IRIS, the EPA's (1997d) Health Effects Assessment Summary Tables (HEAST) was used. For some chemicals, information was not available in IRIS or HEAST, but a footnote in HEAST directed users to contact the Superfund Health Risk Technical Support Center to obtain provisional RfDs. For some chemicals without toxicity values (e.g., 2-nitrophenol and PAHs), a surrogate chemical was used. If toxicity values were not available from any of the above sources, but were presented in the EPA Region IX (1998) PRG table, then these toxicity values were used.

The following PAHs were identified as COPCs: 2-methylnaphthalene, anthracene, benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(g,h,i)perylene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, fluoranthene, indeno(1,2,3-c,d)pyrene, naphthalene, phenanthrene, and pyrene. For the PAH chemical class, oral RfDs exist only for anthracene, fluoranthene, naphthalene, and pyrene. The chronic and subchronic oral RfDs for naphthalene are the lowest and, therefore, the most health protective toxicity values available. Therefore, the naphthalene RfDs were used as surrogates for the noncarcinogenic PAHs lacking oral RfDs (i.e., benzo(g,h,i)perylene, 2-methylnaphthalene, and phenanthrene).

Table 6-5 presents the following noncarcinogenic toxicity data for COPCs evaluated in the site-specific PRE: the oral RfD, the confidence level assigned to the RfD by the EPA, the critical effect selected by the EPA, the UF, the MF, and the source of the noncarcinogenic toxicity data. If information was not available for a chemical and the data for an appropriate surrogate compound could not be identified, "no data" was indicated in the tables. Oral RfDs were not available for 1,2-DCA, 4-bromophenyl phenylether, and lead.

Table 6-5: Toxicity Values: Potential Noncarcinogenic Effects (Oral)

Chemical	Chronic RfD (mg/kg-day)	Subchronic RfD (mg/kg-day)	Confidence Level	Critical Effects	Uncertainty Factor	Modifying Factor
Acetone	1E-01 ^a	1E+00 ^b	Low	Increased liver and kidney weights, and nephrotoxicity (rat)	1,000	1
Anthracene	3E-01 ^a	3E+00 ^b	Low	No observed effects (mouse)	3,000	1
Benzo(a)anthracene	—	—	—	—	—	—
Benzo(a)pyrene	—	—	—	—	—	—
Benzo(b)fluoranthene	—	—	—	—	—	—
Benzo(g,h,i)perylene	2E-02 ^c	2E-01 ^d	—	—	—	—
Benzo(k)fluoranthene	—	—	—	—	—	—
BEHP	2E-02 ^a	2E-02 ^e	Medium	Increased relative liver weight (guinea pig)	1,000	1
4-Bromophenyl-phenylether	—	—	—	—	—	—
2-Butanone	6E-01 ^a	2E+00 ^b	Low	Decreased fetal birth weight (rat)	3,000	1
Butylbenzylphthalate	2E-01 ^a	2E+00 ^b	Low	Significantly increased liver-to-body weight and liver-to-brain weight ratios (rat)	1,000	1
Carbon disulfide	1E-01 ^a	1E-01 ^b	Medium	Fetal toxicity/malformations (rabbit)	100	1
Chrysene	—	—	—	—	—	—
Di-n-butylphthalate	1E-01 ^a	1E+00 ^b	Low	Increased mortality (rat)	1,000	1
Di-n-octylphthalate	2E-02 ^b	2E-02 ^b	—	Increased kidney and liver weight, increased serum glutamic-oxaloacetic transaminase (SGOT) and serum glutamate pyruvate transaminase (SGPT) activity (rat)	1,000	1
Dibenzo(a,h)anthracene	—	—	—	—	—	—
1,2-DCA	—	—	—	—	—	—
Diethyl phthalate	8E-01 ^a	8E+00 ^b	Low	Decreased growth rate, food consumption, and altered organ weights (rat)	1,000	1
Ethylbenzene	1E-01 ^a	1E-01 ^f	Low	Liver and kidney toxicity (rat)	1,000	1
Fluoranthene	4E-02 ^a	4E-01 ^b	Low	Nephropathy, increased liver weights, hematological alterations, and clinical effects	3,000	1
Hexachlorobenzene	8E-04 ^a	8E-04 ^e	Medium	Liver effects (rats)	100	1
Indeno(1,2,3-c,d)pyrene	—	—	—	—	—	—

Chemical	Chronic RfD (mg/kg-day)	Subchronic RfD (mg/kg-day)	Confidence Level	Critical Effects	Uncertainty Factor	Modifying Factor
Lead	—	—	—	—	—	—
2-Methylnaphthalene	2E-02 ^c	2E-01 ^d	—	—	—	—
Naphthalene	2E-02 ^a	2E-01 ^a	Low	Decreased mean terminal body weight (male rat)	3,000	1
2-Nitrophenol	6.2E-02 ^{g,h}	6.2E-02 ^e	—	—	—	—
Phenanthrene	2E-02 ^c	2E-01 ^d	—	—	—	—
Phenol	6E-01 ^a	6E-01 ^b	Low	Reduced fetal body weight (rats)	100	1
Pyrene	3E-02 ^a	3E-01 ^b	Low	Kidney effects (mouse)	3,000	1
1,2,4-Trimethylbenzene	5E-02 ^g	5E-02 ^a	—	—	—	—
1,3,5-Trimethylbenzene	5E-02 ^g	5E-02 ^e	—	—	—	—
Xylenes, total	2E+00 ^a	4E-01 ^f	Medium	Hyperactivity, decreased body weight, and increased mortality (male rat)	100	1

— = no data

^a Retrieved from IRIS database (EPA 1999a).

^b Retrieved from HEAST (EPA 1997d).

^c Chronic RfD for naphthalene was used.

^d Subchronic RfD for naphthalene was used.

^e RfD equal to chronic RfD.

^f Retrieved from Superfund Technical Support Center.

^g Retrieved from EPA Region IX (1998) PRG tables.

^h RfD for 4-nitrophenol was used.

Adjustment of Oral Toxicity Values to Dermal Toxicity Values. For dermal exposure, it is sometimes necessary to adjust an oral toxicity value (i.e., RfD or slope factor) from an administered to an absorbed dose. Thus, an estimated dermally absorbed dose can be appropriately compared with a toxicity value that has been adjusted to a dermal toxicity value.

Oral RfDs or slope factors need to be adjusted for assessment of dermal exposure if the toxicity value is based on an administered dose and if the gastrointestinal absorption of the chemical is less than 50 percent (EPA 1997e). If the chemical has a gastrointestinal absorption of at least 50 percent, a default value of complete oral absorption (i.e., 100 percent) is assumed (EPA 1997e). For all COPCs at offsite investigation area, the gastrointestinal absorption is at least 50 percent. Therefore, complete oral absorption was assumed and adjustment of oral toxicity values was not necessary.

The use of RPFs for assessment of risk from exposure to potentially carcinogenic PAHs should be applied only to oral exposure (EPA 1993a). Therefore, the oral slope factors for the seven PAHs classified as B₂ carcinogens (see Table 6-4) were not used for the assessment of dermal exposure to those COPCs.

6.1.2.4 RISK CHARACTERIZATION

In estimating human health risk, the exposure assessment and the toxicity assessment are integrated into quantitative and qualitative expressions of risk. To characterize risk of potential carcinogenic effects, probabilities that a receptor will develop cancer over a lifetime of exposure are estimated from projected chronic chemical-specific intake or absorbed dose, and chemical-specific slope

factors. Similarly, to characterize risk of potential chronic or subchronic noncarcinogenic effects, comparisons are made between estimated chronic or subchronic intake or absorbed dose, and chemical-specific RfDs. The models used to estimate chronic and subchronic intakes and absorbed doses are shown in Equation 6-1 through Equation 6-4.

For chemicals that are potential carcinogens, risk has been estimated as the incremental probability of a receptor developing cancer over a lifetime as a result of exposure to a potential carcinogen via each identified exposure pathway. The slope factor converts estimated daily intakes to the incremental risk of a receptor developing cancer. The estimated chemical-specific intakes are low compared to intakes experienced by test animals or humans used to compute slope factors. In accordance with EPA guidance, it was assumed that the receptor dose-response relationship is linear in the low-dose portion of the multistage model dose-response curve used to compute slope factors. Using this assumption, the slope factor is considered a constant and cancer risk is related to intake. Therefore, the following equation (i.e., the linear low-dose cancer risk equation) was used to compute chemical-specific cancer risk for each COPC:

$$\text{Risk} = \text{Chronic Daily Intake (CDI)} \times \text{Slope Factor}$$

To estimate risk for the dermal absorption pathway, the estimated absorbed dose was multiplied by the unadjusted oral slope factor. Reasonable maximum case risk was quantified by using RME (intake) values in accordance with EPA guidance. In accordance with EPA guidance, total cancer risk for each exposure pathway was quantified by summing chemical-specific cancer risks (EPA 1989a).

The potential for noncarcinogenic health effects due to chemical exposure is evaluated by comparing intake with an RfD. This comparison, or ratio, is called the hazard quotient and is expressed as the following formula:

$$\text{Hazard Quotient (HQ)} = \frac{\text{Chronic Daily Intake (CDI)}}{\text{Chronic RfD}}$$

To estimate the HQ for the dermal absorption pathway, the estimated absorbed dose was compared with the unadjusted oral RfD. Reasonable maximum case HQs were quantified using RME (intake) values in accordance with EPA guidance.

In accordance with EPA guidance, the HQ for each chemical was summed for each pathway, resulting in a pathway HI (EPA 1989a). This approach is conservative because health effects from exposure to different chemicals may result from a chemical effect on different organ systems.

Summation of screening pathway HQs is appropriate if the chemicals induce the same noncarcinogenic health effects by the same mechanism of action. If the individual HQ for a chemical exceeds 1, then the pathway HI exceeds 1. If two or more chemicals contribute to the pathway HI, addition of chemical HQs may overestimate the potential for health effects if the chemicals do not induce the same health effects by the same mechanism of action.

If more than one chemical contributes to a pathway HI that exceeds 1, then chemicals with similar effects and mechanisms of action are grouped, and the HQs for each chemical in the group are summed to obtain a segregated HI. Segregation of the HQs by health effect and mechanism of action results in HI estimates that are less likely to overestimate noncarcinogenic risk.

Upon completion of the site-specific PRE, the following criteria are used to reach conclusions:

- If the site-specific cumulative RME health risks are below an excess cancer risk of $1\text{E-}06$ (point of departure) and an HI of 1, and if there is no adverse ecological impact, then no further action is recommended.
- If the site-specific cumulative RME excess cancer risk is between $1\text{E-}06$ and $1\text{E-}04$, then the remedial investigation staff and risk assessors recommend the most cost-effective action at the site. The Navy and risk managers decide whether or not to take action on the basis of site-specific conditions, given the concurrence of EPA Region IX.
- If the site-specific cumulative RME health risks slightly exceed the EPA trigger levels for remediation (an RME excess cancer risk of $1\text{E-}04$ and a segregated HI of 1) and there are no isolated, impacted areas where a small removal action could adequately reduce the health risks at the site, then the PRE team recommends a baseline risk assessment. The cost of conducting a baseline risk assessment is compared to the cost of any proposed removal or remedial action. This evaluation is based on professional judgment, and considers factors such as site-specific exposure conditions, land uses, risk-driving COPCs (for example, Class A carcinogens, neurotoxins, or reproductive toxicants), and types of critical effects.
- If the site-specific cumulative RME risk values are so high above the trigger levels for remediation (one order of magnitude or more) that no baseline risk assessment approach can refine the risk estimates to acceptable levels, then the Navy conducts a removal action if such action would not unreasonably impact site ecology.

In other cases, the Navy may determine that additional data are required to arrive at a more conclusive risk assessment for the site because the site is not fully characterized, or more exposure pathways need to be evaluated.

6.2 DISCUSSION OF RESULTS

6.2.1 Screening PRE Results

Chemicals detected in offsite soil or sediment that were included in the human health PRE are presented in Table 6-2. Table 6-6 and Table 6-7 present the results of the residential screening PRE using the methodology discussed in Section 6.1.1. The tables present maximum and RME cumulative excess cancer risk and the maximum and RME cumulative HI. Excess cancer risks and HQs were not estimated for 4-bromophenyl-phenylether (detected in only one sample) because a PRG is not available; this COPC is not included in the tables. Although PRGs are not directly applicable to subsurface soil data, subsurface soil EPCs were conservatively compared to PRGs for this risk assessment.

Because only the cumulative RME risk and HI values are used in the Superfund decision-making process, the following discussion focuses on RME values. The term *risk drivers* is used to refer to COPCs with risk exceeding $1\text{E-}06$ or which contribute to an HI greater than 1.

Table 6-6: Comparison of Offsite Surface Soil or Sediment EPCs to Residential PRGs, EJFDF Phase II RI

COPC	Number of Detects	Sample Size ^a	Frequency of Detection	Max EPC (mg/kg) ^b	95% UCL of Arithmetic Mean (mg/kg)	RME EPC (mg/kg) ^c	Carcinogenic PRG (mg/kg) ^d	Non-Carcinogenic PRG (mg/kg) ^d	Maximum EPC Comparison				RME EPC Comparison						
									Carcinogenic		Noncarcinogenic		Carcinogenic		Noncarcinogenic				
									Excess Cancer Risk ^e	> PRG	% Contribution to Risk	HQ ^f	Excess Cancer Risk ^g	> PRG	% Contribution to Risk	HQ ^h			
VOCs																			
Acetone	6	14	43%	7.48E-02	6.23E-02	6.23E-02	n/a	1.4E+03	n/a	n/a	No	5.3E-05	2%	n/a	n/a	No	4.4E-05	3%	
2-Butanone	4	14	29%	2.89E-02	1.94E-02	1.94E-02	n/a	6.9E-03	n/a	n/a	No	3.9E-06	0%	n/a	n/a	No	2.8E-06	0%	
Carbon disulfide	1	14	7%	8.36E-03	1.17E-02	8.36E-03	n/a	3.5E+02	n/a	n/a	No	2.4E-05	1%	n/a	n/a	No	2.4E-05	2%	
SVOCs																			
Anthracene	2	14	14%	1.20E-02	3.93E-03	3.93E-03	n/a	1.40E+04	n/a	n/a	No	8.6E-07	0%	n/a	n/a	No	2.8E-07	0%	
Benz(a)anthracene	11	14	79%	4.20E-02	3.07E-02	3.07E-02	5.8E-01	n/a	7.5E-08	5%	—	—	—	No	5.5E-08	5%	—	—	
Benz(a)pyrene	9	14	64%	5.00E-02	3.21E-02	3.21E-02	5.8E-02	n/a	9.0E-07	54%	—	—	—	No	5.8E-07	50%	—	—	
Benz(b)fluoranthene	12	14	86%	8.20E-02	3.69E-02	3.69E-02	5.6E-01	n/a	1.5E-07	9%	—	—	—	No	6.6E-08	6%	—	—	
Benz(g,h,i)perylene ⁱ	11	14	79%	1.16E-01	6.46E-02	6.46E-02	n/a	5.5E+01	n/a	n/a	No	2.1E-03	77%	n/a	n/a	No	1.2E-03	74%	
Benz(k)fluoranthene	11	14	79%	6.60E-02	3.17E-02	3.17E-02	5.6E+00	n/a	1.2E-06	1%	—	—	—	No	5.7E-09	0%	—	—	
BEHP	10	14	71%	7.36E-02	2.82E-01	7.36E-02	3.2E+01	1.1E+03	2.3E-09	0%	No	6.7E-05	2%	No	2.3E-09	0%	No	6.7E-05	4%
Chrysene	12	14	86%	7.00E-02	4.86E-02	4.86E-02	5.6E+01	n/a	1.3E-09	0%	—	—	—	No	8.7E-10	0%	—	—	
Dibenz(a,h)anthracene	3	14	21%	2.10E-02	3.29E-01	2.10E-02	5.6E-02	n/a	3.7E-07	23%	—	—	—	No	3.7E-07	33%	—	—	
Diethylphthalate	1	14	7%	4.13E-02	3.95E-01	4.13E-02	n/a	4.4E+04	n/a	n/a	No	9.4E-07	0%	n/a	n/a	No	9.4E-07	0%	
Fluoranthene	12	14	86%	8.40E-02	7.07E-02	7.07E-02	n/a	2.0E+03	n/a	n/a	No	4.2E-05	2%	n/a	n/a	No	3.5E-05	2%	
Indeno(1,2,3-c,d)pyrene	11	14	79%	7.90E-02	3.83E-02	3.83E-02	5.6E-01	n/a	1.4E-07	9%	—	—	—	No	6.8E-08	6%	—	—	
Phenanthrene ^j	9	14	64%	2.10E-02	1.15E-02	1.15E-02	n/a	5.5E+01	n/a	n/a	No	3.9E-04	14%	n/a	n/a	No	2.1E-04	13%	
Phenol	2	14	14%	6.12E-02	3.93E-01	6.12E-02	n/a	3.3E+04	n/a	n/a	No	1.9E-08	0%	n/a	n/a	No	1.9E-08	0%	
Pyrene	11	14	79%	6.60E-02	3.32E-02	3.32E-02	n/a	1.5E+03	n/a	n/a	No	4.4E-05	2%	n/a	n/a	No	2.2E-05	1%	
Inorganics																			
Lead ^k	14	14	100%	5.61E+01	4.59E+01	4.59E+01	n/a	4.0E+02	n/a	n/a	No	n/a	n/a	n/a	n/a	No	n/a	n/a	
Cumulative Cancer Risk:										2E-06	1E-06								
Hazard Index:										3E-03							2E-03		
Note: All concentrations are mg/kg. VOC and SVOC concentrations were converted from reported units of µg/kg by multiplying by the conversion factor of 1 mg = 1,000 µg.																			

Note: All concentrations are mg/kg. VOC and SVOC concentrations were converted from reported units of µg/kg by multiplying by the conversion factor of 1 mg / 1,000 µg.

n/a = not applicable

— = no data

^a Sample size includes duplicates.^b Maximum EPC is the maximum concentration of analyte. Although values shown in the table are rounded, the original values were used in the comparisons with EPA (1999) PRGs.^c RME EPC is the minimum of either the 95 percent UCL of the arithmetic mean or the maximum EPC.^d PRGs are based on cancer risk or noncarcinogenic health effects, unless qualified with a (sat) or (max). Excess cancer risks or HQs are not calculated for chemicals with non-risk-based PRGs.^e Excess Cancer Risk = (1E-06 × Maximum EPC / Carcinogenic PRG)^f HQ = (Maximum EPC / Non-carcinogenic PRG)^g Excess Cancer Risk = (1E-06 × (RME EPC / Carcinogenic PRG))^h HQ = (RME EPC / Noncarcinogenic PRG)ⁱ Naphthalene PRG was used as a surrogate PRG for benzo(g,h,i)perylene and phenanthrene.^j The lead PRG is based on the EPA (1994a) Integrated Exposure Uptake Biokinetic (IEUBK) model. Consequently, an HQ has not been calculated.

Table 6-7: Comparison of Offsite Subsurface Soil EPCs to Residential PRGs, EJFDF Phase II RI

COPC	Number of Detects	Sample Size *	Frequency of Detection	Max EPC (mg/kg) ^b	95% UCL of Arithmetic Mean (mg/kg)	RME EPC (mg/kg) ^c	Carcinogenic PRG (mg/kg) ^d	Non-Carcinogenic PRG (mg/kg) ^d	Maximum EPC Comparison				RME EPC Comparison				
									Carcinogenic		Noncarcinogenic		Carcinogenic		Noncarcinogenic		
									Excess Cancer Risk ^e	> PRG	% Contribution to Risk	HQ ^f	Excess Cancer Risk ^e	> PRG	% Contribution to Risk	HQ ^h	
VOCs																	
Acetone	22	43	51%	1.80E+01	1.90E-01	1.90E-01	n/a	1.4E+03	n/a	n/a	n/a	No	n/a	No	1.4E-04	2%	
2-Butanone	4	43	9%	1.47E-01	1.55E-02	1.55E-02	n/a	6.9E+03	n/a	n/a	n/a	No	n/a	No	2.2E-06	0%	
Carbon disulfide	3	43	7%	1.66E-02	1.23E-02	1.23E-02	n/a	3.5E+02	n/a	n/a	n/a	No	n/a	No	3.5E-05	0%	
1,2-DCA	2	43	5%	3.76E-03	1.17E-02	3.78E-03	3.4E-01	1.9E+01	No	1.1E-08	2%	No	1.1E-08	No	2.0E-04	2%	
Ethylbenzene	2	43	5%	2.64E+00	2.06E-02	2.08E-02	n/a	2.3E+02	n/a	n/a	n/a	No	n/a	No	n/a	n/a	
1,2,4-Trimethylbenzene	4	37	11%	2.85E-01	1.77E-02	1.77E-02	n/a	5.1E+01	n/a	n/a	n/a	No	n/a	No	3.5E-04	4%	
1,3,5-Trimethylbenzene	4	37	11%	2.37E-01	1.78E-02	1.78E-02	n/a	2.1E+01	n/a	n/a	n/a	No	n/a	No	8.5E-04	10%	
Xylenes, total	1	43	2%	3.77E+00	2.32E-02	2.32E-02	n/a	2.1E+02	n/a	n/a	n/a	No	n/a	No	n/a	n/a	
SVOCs																	
Benzo(a)pyrene	4	41	10%	2.33E-02	2.96E-01	2.33E-02	5.6E-02	n/a	No	4.2E-07	74%	—	No	4.2E-07	74%	—	
Benzo(b)fluoranthene	3	41	7%	1.71E-02	2.97E-01	1.71E-02	5.6E-01	n/a	No	3.1E-08	5%	—	No	3.1E-08	5%	—	
Benzo(g,h,i)perylene	5	41	12%	7.99E-02	2.73E-01	7.99E-02	n/a	5.5E+01	n/a	n/a	4%	No	n/a	No	1.5E-03	17%	
BEHP	21	41	51%	5.73E-02	2.12E-01	5.73E-02	3.2E+01	1.1E+03	No	1.8E-09	0%	No	1.8E-09	No	5.2E-05	1%	
Di-n-butylphthalate	10	41	24%	6.11E-02	2.67E-01	6.11E-02	n/a	5.5E+03	n/a	n/a	0%	No	n/a	No	1.1E-05	0%	
Diethylphthalate	5	41	12%	3.05E-02	2.84E-01	3.05E-02	n/a	4.4E+04	n/a	n/a	0%	No	n/a	No	6.9E-07	0%	
Hexachlorobenzene	1	41	2%	2.82E-02	2.43E-01	2.82E-02	2.8E-01	n/a	No	1.0E-07	18%	—	No	1.0E-07	18%	—	
2-Methylnaphthalene ¹	1	41	2%	3.94E-02	2.38E-01	3.94E-02	n/a	5.5E+01	n/a	n/a	2%	No	n/a	No	7.2E-04	8%	
Naphthalene	1	41	2%	1.02E-02	2.66E-01	1.02E-02	n/a	5.5E+01	n/a	n/a	0%	No	n/a	No	1.8E-04	2%	
2-Nitrophenol ²	1	43	2%	1.55E-02	2.52E-01	1.55E-02	n/a	3.4E+00	n/a	n/a	12%	No	n/a	No	4.5E-03	53%	
Phenol	1	43	2%	1.87E-02	2.48E-01	1.87E-02	n/a	3.3E+04	n/a	n/a	0%	No	n/a	No	5.7E-07	0%	
Pyrene	1	41	2%	3.63E-02	2.39E-01	3.63E-02	n/a	1.5E+03	n/a	n/a	0%	No	n/a	No	2.6E-05	0%	
TPH																	
C08-C11 (Gasoline Range)	1	43	2%	1.50E+00	1.40E+00	1.40E+00	n/a	2.0E+03 ³	n/a	n/a	n/a	No	n/a	No	n/a	n/a	
Inorganics																	
Lead ⁴	42	43	98%	1.30E+01	2.79E+00	2.79E+00	n/a	4.0E+02	n/a	n/a	n/a	No	n/a	No	n/a	n/a	
Cumulative Cancer Risk:																	
										6E-07	4E-02						9E-03
Hazard Index:																	

Note: All concentrations are mg/kg. VOC and SVOC concentrations were converted from reported units of µg/kg by multiplying by the conversion factor of 1 mg / 1,000 µg.

n/a = not applicable; — = no data

^a Sample size includes duplicates.^b Maximum EPC is the maximum concentration of analyte. Although values shown in the table are rounded, the original values were used in the comparisons with EPA (1998) PRGs.^c RME EPC is the minimum of either the 95 percent UCL of the arithmetic mean or the maximum EPC.^d PRGs are based on cancer risk or noncarcinogenic health effects, unless qualified with a (sat) or (max). Excess cancer risks or HQs are not calculated for chemicals with non-risk-based PRGs.^e Excess Cancer Risk = (1E-06 x Maximum EPC / Carcinogenic PRG)^f HQ = (Maximum EPC / Noncarcinogenic PRG)^g Excess Cancer Risk = (1E-06 x (RME EPC / Carcinogenic PRG))^h HQ = (RME EPC / Noncarcinogenic PRG)ⁱ Naphthalene PRG was used as a surrogate PRG for benzo(g,h,i)perylene and 2-methylnaphthalene.^j 4-Nitrophenol was used as a surrogate PRG for 2-nitrophenol.^k The value listed for the TPH noncarcinogenic PRG is an ARAH and is not risk-based.^l The lead PRG is based on the EPA (1994a) Integrated Exposure Uptake Biokinetic (IEUBK) model. Consequently, an HQ has not been calculated.

6.2.1.1 RESIDENTIAL LAND USE SCENARIO: CURRENT AND FUTURE RISK TO RESIDENTS FROM EXPOSURE TO SURFACE SOIL OR SEDIMENT

For exposure to contaminants in offsite surface soil or sediment, the cumulative RME excess cancer risk is $1\text{E-}06$ and the HI is $2\text{E-}03$, as shown in Table 6-6. Both adult and child exposures are addressed through use of the residential soil PRGs. The excess cancer risk does not significantly exceed the point of departure risk value of $1\text{E-}06$ at $1.15\text{E-}06$, and is less than the trigger level for remediation of $1\text{E-}04$. The HI is less than the level of concern of 1. There are no carcinogenic or noncarcinogenic risk drivers. The lead RME EPC of 45.9 mg/kg is less than the residential PRG of 400 mg/kg. Offsite residential exposure to surface soil and sediment contaminants is considered acceptable.

For exposure to contaminants in offsite subsurface soil, the cumulative RME excess cancer risk is $6\text{E-}07$ and the HI is $9\text{E-}03$, as shown in Table 6-7. The excess cancer risk is less than the point of departure risk value of $1\text{E-}06$, and the HI is less than the level of concern of 1. There are no carcinogenic or noncarcinogenic risk drivers. The RME EPC of lead (2.79 mg/kg) is less than the residential PRG of 400 mg/kg. The RME EPC of TPH-gasoline (1.4 mg/kg) is less than the DOH UST screening guideline of 2,000 mg/kg (Tier 1 action level). Offsite residential exposure to subsurface soil contaminants is considered acceptable.

6.2.2 Site-Specific PRE Results

Results of the site-specific PRE for exposure of current and future receptors to contaminants in offsite surface soil, sediment, subsurface soil, and surface water are presented below. The site-specific PRE was conducted for the following pathways:

- Dermal contact with contaminants in offsite surface water by current and future farm workers
- Ingestion of water/cress by all identified receptors, i.e., farm workers, residents (adult and child), and utility workers
- Ingestion of and dermal contact with contaminants in offsite soil (i.e., surface soil, sediment, and subsurface soil) by future utility workers.

6.2.2.1 FARM WORKERS: CURRENT AND FUTURE RISK FROM EXPOSURE TO SURFACE WATER

Any chemical detected in offsite surface water at least once was considered a COPC, as shown in Table 6-2. Risk and HI were estimated using RME EPCs and the intake model presented in Equation 6-1. Table 6-8 and Table 6-9 present the results of the site-specific PRE for farm workers exposed to contaminants in the watercress fields (also see Appendix N, Table N-3). The site-specific RME cumulative cancer risk (5E-11) is less than 1E-06. A slope factor was available for only one of the ten carcinogenic COPCs in surface water, BEHP. The RME HI (3E-02) is less than the level of concern of 1.

Table 6-8: Estimated Surface Water Cancer Risks for Farm Workers in the Offsite Investigation Area (Reasonable Maximum Case, Dermal Absorption of Chemicals, Current and Future Land Use)

Chemical	RME (mg/kg-day) ^a	Slope Factor (mg/kg-day) ⁻¹	Weight of Evidence ^b	Chemical-Specific Risk
SVOCs				
Benzo(a)anthracene	9.44E-05	—	B ₂	—
Benzo(a)pyrene	1.07E-04	—	B ₂	—
Benzo(b)fluoranthene	1.17E-04	—	B ₂	—
Benzo(k)fluoranthene	1.03E-07	—	B ₂	—
BEHP	3.48E-09	1.4E-02	B ₂	4.9E-11
Butylbenzylphthalate	2.06E-08	—	C	—
Chrysene	1.29E-04	—	B ₂	—
Dibenzo(a,h)anthracene	3.86E-06	—	B ₂	—
Indeno(1,2,3-c,d)pyrene	1.30E-04	—	B ₂	—
Inorganics				
Lead	5.59E-07	—	B ₂	—
Total Pathway Risk				5E-11

Note: Site COPCs not designated as carcinogens by EPA are not included.

— = no data

^a See Appendix N, Table N-3.

^b See Table 6-3 for definitions.

**Table 6-9: Estimated Surface Water HQs for Farm Workers in the Offsite Investigation area
(Reasonable Maximum Case, Dermal Absorption of Chemicals, Current and Future Land Use)**

Chemical	RME (mg/kg-day) ^a	Reference Dose (mg/kg-day)	Adjusted for Absorption	Hazard Quotient
SVOCs				
Benzo(a)anthracene	2.64E-04	—	No	—
Benzo(a)pyrene	3.00E-04	—	No	—
Benzo(b)fluoranthene	3.27E-04	—	No	—
Benzo(g,h,i)perylene	2.64E-07	2E-02	No	1.3E-05
Benzo(k)fluoranthene	2.88E-07	—	No	—
BEHP	9.74E-09	2E-02	No	4.9E-07
Butylbenzylphthalate	5.77E-08	2E-01	No	2.9E-07
Chrysene	3.61E-04	—	No	—
Di-n-octylphthalate	2.08E-08	2E-02	No	1.0E-06
Dibenzo(a,h)anthracene	1.08E-05	—	No	—
Fluoranthene	5.82E-04	4E-02	No	1.5E-02
Indeno(1,2,3-c,d)pyrene	3.65E-04	—	No	—
2-Nitrophenol	1.54E-06	—	No	—
Phenanthrene	3.85E-04	2E-02	No	1.9E-02
Pyrene	6.49E-07	3E-02	No	2.2E-05
Inorganics				
Lead	1.56E-06	—	No	—
Total Pathway Hazard Index				3E-02

— = no data

^a See Appendix N, Table N-3.

6.2.2.2 ALL RECEPTORS: CURRENT AND FUTURE RISK FROM INGESTION OF WATERCRESS

Any chemical detected in surface soil/sediment at least once was considered a COPC. Risk and HI were estimated using the RME EPCs and the intake model presented in Equation 6-2. (Exposure parameter values for ingestion of watercress were age-adjusted to reflect child as well as adult exposures.) Table 6-10 and Table 6-11 present the results of the site-specific PRE for receptors who ingest watercress (also see Appendix N, Table N-4). The site-specific RME cumulative cancer risk ($3\text{E}-10$) is less than $1\text{E}-06$. The RME HI ($3\text{E}-06$) is less than the level of concern of 1.

Table 6-10: Estimated Cancer Risks for All Receptors (Reasonable Maximum Case, Ingestion of Watercress, Current and Future Land Use)

Chemical	RME (mg/kg-day) ^a	Slope Factor (mg/kg-day) ⁻¹	Weight of Evidence ^b	Chemical-Specific Risk
SVOCs				
Benzo(a)anthracene	2.75E-11	7.3E-01	B ₂	2.0E-11
Benzo(a)pyrene	1.73E-11	7.3E+00	B ₂	1.3E-10
Benzo(b)fluoranthene	2.84E-11	7.3E-01	B ₂	2.1E-11
Benzo(k)fluoranthene	2.29E-11	7.3E-02	B ₂	1.7E-12
BEHP	2.31E-13	1.4E-02	B ₂	3.2E-15
Chrysene	4.50E-11	7.3E-03	B ₂	3.3E-13
Dibenzo(a,h)anthracene	1.35E-11	7.3E+00	B ₂	9.9E-11
Indeno(1,2,3-c,d)pyrene	1.55E-11	7.3E-01	B ₂	1.1E-11
Inorganics				
Lead	1.12E-07	—	B ₂	—
Total Pathway Risk				3E-10

Note: Site COPCs not designated as carcinogens by EPA are not included.

— = no data

^a See Appendix N, Table N-4.

^b See Table 6-3 for definitions.

Table 6-11: Estimated HQs for All Receptors (Reasonable Maximum Case, Ingestion of Watercress, Current and Future Land Use)

Chemical	RME (mg/kg-day) ^a	Reference Dose (mg/kg-day)	Adjusted for Absorption	Hazard Quotient
VOCs				
Acetone	2.71E-07	1E-01	No	2.7E-06
2-Butanone	1.23E-08	6E-01	No	2.0E-08
Carbon disulfide	3.87E-10	1E-01	No	3.9E-09
SVOCs				
Anthracene	3.71E-11	3E-01	No	1.2E-10
Benzo(a)anthracene	6.41E-11	—	No	—
Benzo(a)pyrene	4.04E-11	—	No	—
Benzo(b)fluoranthene	6.63E-11	—	No	—
Benzo(g,h,i)perylene	5.34E-11	2E-02	No	2.7E-09
Benzo(k)fluoranthene	5.34E-11	—	No	—
BEHP	5.40E-13	2E-02	No	2.7E-11
4-Bromophenyl-phenylether	1.68E-10	—	No	—
Chrysene	1.05E-10	—	No	—
Dibenzo(a,h)anthracene	3.16E-11	—	No	—
Diethylphthalate	1.04E-09	8E-01	No	1.3E-09
Fluoranthene	3.27E-10	4E-02	No	8.2E-09
Indeno(1,2,3-c,d)pyrene	3.63E-11	—	No	—
Phenanthrene	1.46E-10	2E-02	No	7.3E-09
Phenol	5.84E-09	6E-01	No	9.7E-09
Pyrene	1.46E-10	3E-02	No	4.9E-09
Inorganics				
Lead	2.60E-07	—	No	—
Total Pathway Hazard Index				3E-06

— = no data

^a See Appendix N, Table N-4.

6.2.2.3 UTILITY WORKERS: FUTURE RISK FROM EXPOSURE TO SOIL

Utility workers could contact surface soil, sediment, and subsurface soil. Consequently, data collected from all sampled depths were combined to determine EPCs because these data are considered representative of soil contacted by utility workers. Any chemical detected at least once was considered a COPC. Risk and HI were estimated using the maximum and RME EPCs and the intake models presented in Equation 6-3 and Equation 6-4. Table 6-12 through Table 6-15 present the results of the site-specific PRE for future utility workers (see also Appendix N, Tables N-5 and N-6). The RME cumulative cancer risk ($9\text{E}-10$) is less than $1\text{E}-06$. The RME HI ($3\text{E}-04$) is less than the level of concern of 1.

Table 6-12: Estimated Cancer Risks for Utility Workers in the Offsite Investigation Area (Reasonable Maximum Case, Ingestion of Chemicals in Soil, Future Land Use)

Chemical	RME (mg/kg-day) ^a	Slope Factor (mg/kg-day) ⁻¹	Weight of Evidence ^b	Chemical-Specific Risk
VOCs				
Carbon disulfide	$1.50\text{E}-11$	—	—	—
1,2-DCA	$4.92\text{E}-11$	$9.1\text{E}-02$	B ₂	$4\text{E}-12$
SVOCs				
Benzo(a)anthracene	$5.49\text{E}-11$	$7.3\text{E}-01$	B ₂	$4\text{E}-11$
Benzo(a)pyrene	$6.54\text{E}-11$	$7.3\text{E}+00$	B ₂	$5\text{E}-10$
Benzo(b)fluoranthene	$1.07\text{E}-10$	$7.3\text{E}-01$	B ₂	$8\text{E}-11$
Benzo(k)fluoranthene	$8.63\text{E}-11$	$7.3\text{E}-02$	B ₂	$6\text{E}-12$
Bis-(2-ethylhexyl)phthalate	$9.63\text{E}-11$	$1.4\text{E}-02$	B ₂	$1\text{E}-12$
Chrysene	$9.16\text{E}-11$	$7.3\text{E}-03$	B ₂	$7\text{E}-13$
Dibenzo(a,h)anthracene	$2.74\text{E}-11$	$7.3\text{E}+00$	B ₂	$2\text{E}-10$
Hexachlorobenzene	$3.68\text{E}-11$	$1.6\text{E}+00$	B ₂	$6\text{E}-11$
Indeno(1,2,3-c,d)pyrene	$1.03\text{E}-10$	$7.3\text{E}-01$	B ₂	$8\text{E}-11$
Naphthalene	$1.33\text{E}-11$	—	C	—
Inorganics				
Lead	$1.29\text{E}-08$	—	B ₂	—
Total Pathway Risk				$9\text{E}-10$

Note: Site COPCs not designated as carcinogens by EPA are not included.

— = no data

^a See Appendix N, Table N-5.

^b See Table 6-3 for definitions.

Table 6-13: Estimated Cancer Risks for Utility Workers in the Offsite Investigation Area (Reasonable Maximum Case, Dermal Absorption of Chemicals in Soil, Future Land Use)

Chemical	Reasonable Maximum Exposure (mg/kg-day) ^a	Slope Factor (mg/kg-day) ⁻¹	Weight of Evidence ^b	Chemical-Specific Risk
VOCs				
Carbon disulfide	1.47E-12	—	—	—
1,2-DCA	4.79E-12	9.1E-02	B ₂	4E-13
SVOCs				
Benzo(a)anthracene	5.35E-12	—	B ₂	—
Benzo(a)pyrene	6.37E-12	—	B ₂	—
Benzo(b)fluoranthene	1.04E-11	—	B ₂	—
Benzo(k)fluoranthene	8.41E-12	—	B ₂	—
Bis-(2-ethylhexyl)phthalate	9.38E-12	1.4E-02	B ₂	1E-13
Chrysene	8.92E-12	—	B ₂	—
Dibenzo(a,h)anthracene	2.67E-12	—	B ₂	—
Hexachlorobenzene	3.59E-12	1.6E+00	B ₂	6E-12
Indeno(1,2,3-c,d)pyrene	1.01E-11	—	B ₂	—
Naphthalene	1.29E-12	—	C	—
Inorganics				
Lead	1.26E-09	—	B ₂	—
Total Pathway Risk				6E-12
Total RME Excess Cancer Risk				9E-10

Note: Site COPCs not designated as carcinogens by EPA are not included.

— = no data

^a See Appendix N, Table N-6.

^b See Table 6-3 for definitions.

Table 6-14: Estimated HQs for Utility Workers in the Offsite Investigation Area (Reasonable Maximum Case, Ingestion of Chemicals in Soil, Future Land Use)

Chemical	Reasonable Maximum Exposure (mg/kg-day) ^a	Reference Dose (mg/kg-day) ^b	Hazard Quotient
VOCs			
Acetone	7.75E-07	1E+00	8E-07
2-Butanone	1.00E-07	2E+00	5E-08
Carbon disulfide	7.69E-08	1E-01	8E-07
1,2-DCA	2.51E-07	—	—
Ethylbenzene	1.15E-07	1E-01	1E-06
1,2,4-Trimethylbenzene	1.04E-07	5E-02	2E-06
1,3,5-Trimethylbenzene	1.05E-07	5E-02	2E-06
Xylenes, total	1.24E-07	4E-01	3E-07
SVOCs			
Anthracene	8.02E-08	3E+00	3E-08
Benzo(a)anthracene	2.81E-07	—	—
Benzo(a)pyrene	3.34E-07	—	—
Benzo(b)fluoranthene	5.48E-07	—	—
Benzo(g,h,i)perylene	7.73E-07	2E-01	4E-06
Benzo(k)fluoranthene	4.41E-07	—	—
Bis-(2-ethylhexyl)phthalate	4.92E-07	2E-02	2E-05
4-Bromophenyl-phenylether	1.32E-06	—	—
Chrysene	4.68E-07	—	—
Di-n-butylphthalate	4.08E-07	1E+00	4E-07
Dibenzo(a,h)anthracene	1.40E-07	—	—
Diethylphthalate	2.76E-07	8E+00	3E-08
Fluoranthene	5.62E-07	4E-01	1E-06
Hexachlorobenzene	1.88E-07	8E-04	2E-04
Indeno(1,2,3-c,d)pyrene	5.28E-07	—	—
2-Methylnaphthalene	2.63E-07	2E-01	1E-06
Naphthalene	6.79E-08	2E-01	3E-07
2-Nitrophenol	1.03E-07	6E-02	2E-06
Phenanthrene	1.40E-07	2E-01	7E-07
Phenol	4.09E-07	6E-01	7E-07
Pyrene	4.41E-07	3E-01	1E-06
Inorganics			
Lead	6.59E-05	—	—
Total Pathway Hazard Index			3E-04

— = no data

^a See Appendix N, Table N-5.^b See Table 6-3 for definitions.

Table 6-15: Estimated HQs for Utility Workers in the Offsite Investigation Area (Reasonable Maximum Case, Dermal Absorption of Chemicals in Soil, Future Land Use)

Chemical	Reasonable Maximum Exposure (mg/kg-day) ^a	Reference Dose (mg/kg-day)	Adjusted for Absorption	Hazard Quotient
VOCs				
Acetone	7.55E-08	1E+00	No	8E-08
2-Butanone	9.76E-09	2E+00	No	5E-09
Carbon disulfide	7.49E-09	1E-01	No	7E-08
1,2-DCA	2.45E-08	—	No	—
Ethylbenzene	1.12E-08	1E-01	No	1E-07
1,2,4-Trimethylbenzene	1.02E-08	5E-02	No	2E-07
1,3,5-Trimethylbenzene	1.02E-08	5E-02	No	2E-07
Xylenes, total	1.21E-08	4E-01	No	3E-08
SVOCs				
Anthracene	7.81E-09	3E+00	No	3E-09
Benzo(a)anthracene	2.73E-08	—	No	—
Benzo(a)pyrene	3.25E-08	—	No	—
Benzo(b)fluoranthene	5.34E-08	—	No	—
Benzo(g,h,i)perylene	7.53E-08	2E-01	No	4E-07
Benzo(k)fluoranthene	4.30E-08	—	No	—
Bis-(2-ethylhexyl)phthalate	4.79E-08	2E-02	No	2E-06
4-Bromophenyl-phenylether	1.28E-07	—	No	—
Chrysene	4.56E-08	—	No	—
Di-n-butylphthalate	3.98E-08	1E+00	No	4E-08
Dibenzo(a,h)anthracene	1.37E-08	—	No	—
Diethylphthalate	2.69E-08	8E+00	No	3E-09
Fluoranthene	5.47E-08	4E-01	No	1E-07
Hexachlorobenzene	1.83E-08	8E-04	No	2E-05
Indeno(1,2,3-c,d)pyrene	5.14E-08	—	No	—
2-Methylnaphthalene	2.56E-08	2E-01	No	1E-07
Naphthalene	6.61E-09	2E-01	No	3E-08
2-Nitrophenol	1.01E-08	6E-02	No	2E-07
Phenanthrene	1.37E-08	2E-01	No	7E-08
Phenol	3.98E-08	6E-01	No	7E-08
Pyrene	4.30E-08	3E-01	No	1E-07
Inorganics				
Lead	6.42E-06	—	No	—
Total Pathway Hazard Index				3E-05
Total RME Hazard Index				3E-04

— = no data

^a See Appendix N, Table N-6.

6.2.3 Uncertainty Analysis

6.2.3.1 UNCERTAINTIES IN EXPOSURE ASSESSMENT

Uncertainty in the exposure assessment is a function of the completeness of site data, accuracy of EPCs, assumptions that simplify and approximate actual current or future site conditions, and professional judgment used in developing and evaluating various parameters. Each of these elements of uncertainty is described below.

It was assumed in the exposure assessment that chemical concentrations in site soil, sediment, or surface water would remain constant and that the transport mechanisms would operate at a steady state. This means that contaminant levels will not decrease due to the exhaustion of the contaminant sources or reach higher concentrations over the assumed exposure periods. One result of this assumption may be overestimation of future EPCs near source areas, because contaminant sources would likely decrease over time due to transport and fate mechanisms, such as migration, photo-oxidation, and biodegradation.

An assumption made in the exposure assessment is that chemicals of concern are uniformly distributed over the defined area, thus resulting in a uniform exposure level. Chemical analytical data were obtained from a biased sampling program; sampling locations were generally selected on the basis of where contaminants were expected to be present. Sampling zones likely to be free of contamination received less investigation. This type of sampling scheme tends to overestimate a site's overall chemical concentration distribution and resultant exposure and risk values.

It should be noted that the surface water EPCs are based on data from a single surface water sample (W-06). This sample was collected from a drainage channel, not from the watercress fields. Therefore, it is not representative of concentrations likely to be contacted frequently by farm workers.

Use of the H-statistic to calculate the 95 percent UCL of the arithmetic mean concentrations of COPCs tends to overestimate EPCs. However, this statistical approach is conservative and appropriate for the screening PRE.

Exposure scenarios and health protective exposure factors presented in this risk assessment are generally conservative and overestimate rather than underestimate exposure. It is assumed that human exposure remains constant over the lifetime of an individual. In fact, lifestyle changes due to age and actual residence time will alter the projected exposure durations. Movement of individuals in and out of the potentially exposed community also affects exposure duration.

The utility worker exposure scenario is considered very conservative because subsurface soil data from depths as great as 32 feet bgs were used. It is unlikely that any utility worker would work at these depths. However, because chemicals related to the MOGAS release are more likely to be encountered within the deeper subsurface soils than within the 0–5 foot depth interval, the site-specific PRE included the deeper subsurface soil data.

6.2.3.2 UNCERTAINTIES IN TOXICITY ASSESSMENT

Slope factors developed by the EPA are generally conservative, and represent the upper bound limit (i.e., upper 95th percent confidence limit) of the probability of a cancer response. Thus, the actual carcinogenic risk due to exposure to selected chemicals is likely to be lower than the estimated risk.

RfDs developed by the EPA are generally considered to have uncertainty spanning an order of magnitude or more. Consequently, total HIs for human receptors may be estimated high or low by an order of magnitude or more. The EPA reports a "level of confidence" for each RfD. Low confidence

suggests a high degree of uncertainty in the accuracy of the toxicity value, and indicates that the value may change in the future if additional toxicity data becomes available. Conversely, high confidence by the EPA in an RfD or a reference concentration (RfC) indicates low uncertainty in the accuracy of the toxicity value. Uncertainty and modifying factors used to develop RfDs are presented in Table 6-5.

6.2.3.3 UNCERTAINTIES IN RISK ESTIMATION

An oral RfD was lacking for 1,2-DCA and 4-bromophenyl-phenylether; lack of a RfD may cause an underestimation of the adversity of noncarcinogenic health effects.

Uncertainty in the evaluation of carcinogenic risk and noncarcinogenic hazard due to PAHs in surface water and soil is influenced by a lack of toxicity values. The oral slope factor for benzo(a)pyrene was used as a surrogate, employing RPFs from EPA (1993a) guidance, for the six other PAHs classified as B₂ carcinogens: (benzo(a)anthracene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, dibenzo(a,h)anthracene, and indeno(1,2,3-cd)pyrene). However, route-to-route extrapolation from the oral to dermal routes of exposure is not appropriate for the PAHs, which are known to elicit direct toxic effects on the skin (EPA 1993a). Therefore, potential carcinogenic risks due to dermal exposure to PAHs in surface water (farm workers) and soil/sediment (utility workers) may be underestimated because of a lack of appropriate toxicity values. In addition, oral and dermal reference doses were not available for these seven carcinogenic PAHs, potentially underestimating the noncarcinogenic hazards associated with exposures to those COPCs.

Many of the COPCs in surface water and soil/sediment are PAHs. The HMW PAHs detected in the offsite area are not likely to be associated with the 1971 MOGAS release or with residual onsite subsurface soil contamination for the following reasons:

- The PAHs detected offsite are C16–C22 hydrocarbons, not the C6–C12 hydrocarbons associated with gasoline products (such as BTEX and naphthalene compounds). Lighter hydrocarbons do not naturally transform or degrade to heavier hydrocarbons (e.g., via photolysis, hydrolysis, or biodegradation) (Lyman et al. 1982).
- No direct pathway is available to transport onsite subsurface soil contaminants from the MOGAS source area to the offsite watercress fields. Hydrogeological evidence and analytical data indicate that caprock groundwater does not reach the surface in the watercress farm area and does not discharge to the confined basal aquifer, which supplies water to the watercress fields. Furthermore, PAHs are relatively immobile in the aqueous phase due to their low solubility and high affinity for organic matter.
- The PAHs detected offsite are very common in urban environments and could be associated with automotive exhaust, asphalt pavement, and surface runoff from Waiawa Road or other asphalt-paved surfaces. They could also be associated with the underground fuel pipelines that cross the area (see discussion in Section 3.6), fill storage piles, abandoned buses, and heavy equipment operations, maintenance, and storage areas (e.g., the Okada Trucking site; see Figure 3.1).

6.3 PRE CONCLUSIONS

Table 6-16 presents a summary of total human cancer risk and HIs resulting from exposure to contaminants detected in the offsite areas. There are no complete pathways for exposure of offsite receptors to residual onsite subsurface soil contamination from the 1971 MOGAS release. Therefore, there are no risks associated with this source. As noted in Table 6-16, cumulative RME cancer risks are all below an excess cancer risk of 1E-06 (the point of departure risk value) and noncarcinogenic

hazard indices are all below 1 (the HI level of concern). Therefore, no risk drivers were identified in the human health PRE.

Table 6-16: Total Human Receptor Cancer Risks and Hazard Indexes

Receptor/Source	Maximum Case	Reasonable Maximum Case	Receptor at Risk? ^a	Chemicals Contributing to Risk
CANCER RISKS				
Current and Future Farm Workers				
Surface water	n/a	5E-11	No	n/a
Current and Future Residents				
Surface soil and sediment	2E-06	1E-06	No	n/a
Subsurface soil	6E-07	6E-07	No	n/a
Current and Future Receptors (All)				
Ingestion of watercress	n/a	3E-10	No	n/a
Future Utility Workers				
All soil and sediment	n/a	9E-10	No	n/a
HAZARD INDEXES				
Current and Future Farm Workers				
Surface water	n/a	3E-02	No	n/a
Current and Future Residents				
Surface soil and sediment	3E-03	2E-03	No	n/a
Subsurface soil	4E-02	9E-03	No	n/a
Current and Future Receptors (All)				
Ingestion of watercress	n/a	3E-06	No	n/a
Future Utility Workers				
All soil and sediment	n/a	3E-04	No	n/a

n/a = not applicable; the maximum case risk and HI were calculated only for residents. Where no receptors were at risk, there were no chemicals contributing to risk.

^a For cancer risk, > 1E-06; for hazard index, HI > 1.

7. ECOLOGICAL RISK ASSESSMENT

The ecological risk assessment (ERA) conducted for the Phase II RI is intended to supplement the screening ecological risk assessment presented in the Phase I RI. Due to the lack of offsite wells and surface water and sediment sampling downgradient from the EJFDF in the Phase I RI, there was unacceptable uncertainty in the potential for exposure of wildlife (including the federally endangered Hawaii black-necked stilt) to site contaminants in the agricultural wetlands. The wetland area is located south of the site between the south property boundary and the shoreline of Pearl Harbor Middle Loch. The intent of this Tier 2 ecological risk assessment was to assess risks to the environment associated with exposure to chemicals that may have migrated from the EJFDF to the offsite watercress farm area. However, Phase II RI findings indicate that the risk drivers detected in the offsite area (lead and PAHs) are not related to the EJFDF MOGAS release. The ERA focused on potential risks to ecological receptors that inhabit or utilize the wetland and upland habitats in the watercress farm area. Based on the risk estimates, uncertainty, and consideration of the bioavailability of PAHs detected off site, risk to ecological receptors in the offsite area downgradient of the EJFDF is considered acceptable.

The ERA conducted for the Phase I RI assessed environmental risks associated with exposure to chemicals detected within the boundaries of the EJFDF (Ogden 1996). Chemicals of potential ecological concern (COPECs) and potential ecological receptors were identified during the Phase I RI. An ERA was then conducted to identify complete or potentially complete exposure pathways and to assess risks to ecological receptors, both on site and in the offsite agricultural wetlands area (watercress fields). The surface soils did not contain COPECs at concentrations high enough to present a risk to onsite terrestrial receptors.

Although there was no solid evidence that groundwater from beneath the site (caprock water-bearing zone) discharged into the terraced watercress fields and associated wetlands, modeling of COPEC transport to ecological receptors in the agricultural wetlands showed that risk to wetland species from potential COPEC exposure was acceptable. Because the watercress fields are continually flooded by the flow of water from artesian wells installed in the confined basal aquifer, it was impossible to determine whether the caprock water-bearing zone discharges into the watercress fields without measurements from nearby wells installed in the caprock water-bearing zone. One of the objectives of the Phase II RI offsite investigation was to install offsite wells to establish the groundwater elevations in the agricultural wetland area and collect subsurface soil and groundwater samples for chemical analysis. The analytical results were used to assess the potential presence of site-related COPECs in the offsite caprock groundwater. Hydrogeological evidence from the wells was used to evaluate the potential for caprock ground water to discharge into the watercress fields or the tidal ditches that drain excess water flow from the fields.

The Phase I RI ERA concluded that COPECs detected in the caprock groundwater may be transported to the marine environment in the Middle Loch of Pearl Harbor. However, natural attenuation along the groundwater flow path and dilution that occurs when the groundwater is discharged to Middle Loch will tend to minimize risk to ecological receptors. Phase I RI ERA risk estimates indicated minimal potential for adverse effects to either marine invertebrates or shorebirds, even if it is assumed that COPECs in caprock groundwater are diluted only after they enter Middle Loch.

The Phase I RI ERA was conducted in 1995 and 1996 using guidelines then in effect. This Phase II RI ERA was conducted in accordance with current national guidance for evaluating ecological risks at hazardous waste sites. According to the latest EPA (1997a) guidance, ecological risk assessment is an eight-step process (see Figure 7-1). Steps 1 and 2 in this process constitute a screening ecological risk assessment (SERA). Steps 3 through 7 constitute guidance for conducting a baseline ERA.

(BERA). The Navy also has established policy for conducting ecological risk assessment at Navy sites (DON 1999). Navy policy includes a tiered approach that integrates the EPA 8-step process (Figure 7-2). Tier 1 includes EPA Steps 1 and 2 (SERA); Tier 2 includes Steps 3 through 7 (BERA); and Tier 3 addresses evaluation of remedial alternatives. This includes considerations that go beyond the risk assessment process, into the realm of risk management (EPA Step 8, in part). It is also Navy policy that risk assessments already under way meet the substantive requirements of the tiered approach.

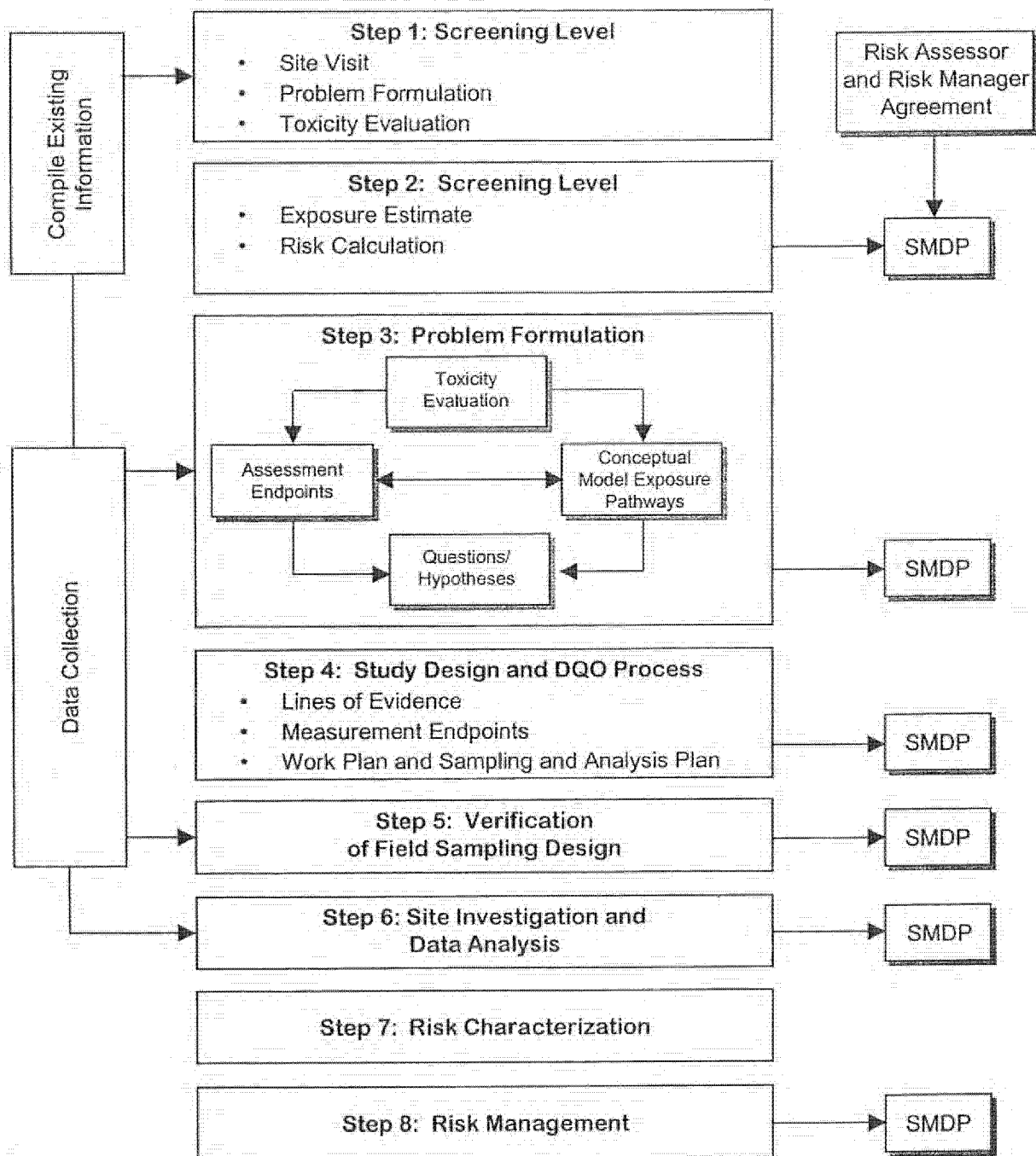
Because this ERA is part of a Phase II RI, it has been designed to fill data gaps and reduce uncertainties identified in the Phase I ERA. As such, it contains elements of a Tier 2 ERA. A major data gap addressed by this Phase II RI is the nature and extent of site-related contamination that may have migrated off the Navy property into the agricultural wetlands. This includes a detailed analysis of surface water flow in the offsite area and collection of bulk sediment and surface water samples for chemical analysis. The Navy is conducting further evaluation of potential impacts to Pearl Harbor under a separate investigation (Pearl Harbor Sediment Study). Therefore, sampling of Middle Loch sediments and surface water under this Phase II RI was limited to two shoreline samples at discharge points in the mangrove swamp south of the bike path and three samples in the tidal drainage ditches north of the bike path.

The new analytical data were screened using the Navy Tier 1 methodology and further evaluated in the context of the Phase I RI using Tier 2 elements (up to Step 3a) as follows:

- Tier 1, Step 1 included problem formulation; describing the ecological setting of the EJFDF; and identifying ecological receptors, chemicals of concern, and assessment and measurement endpoints. It also included an analysis of exposure pathways and development of a CSM. Finally, Step 1 included an evaluation of the toxicity of potential COPECs.
- Tier 1, Step 2 is the effects evaluation. The effects evaluation included calculation of EPCs, models of potential intake values (dose), and exposure estimation. NOAEL-based toxicity reference values (TRVs) and exposure equations were used to back-calculate a safe soil screening level (SSL) for each potential COPEC. Media concentrations (surface water, sediment, and soil) were compared to media screening values using the hazard quotient (HQ) methodology. The risk calculation section presented the HQ analysis used to predict the potential for adverse effects to ecological receptors. Finally, a comprehensive uncertainty analysis covering each step of the risk assessment was presented.

Risk characterization requires analysis of the potential for adverse effects to representative species in light of the uncertainties inherent in the risk assessment process. The uncertainties were weighed to decide whether a potential for adverse effects is likely to represent an unacceptable risk to the environment. Section 7.3.4 contains a brief summary and recommendations.

In Tier 2, the results of the Phase II RI ERA were evaluated further in the context of the Phase I RI results (Ogden 1996), where the refined understanding of offsite exposure was incorporated into the results of the onsite investigation.



Key:

DQO - Data Quality Objective

SMDP - Scientific/Management Decision Point

Figure 7-1
Eight-Step Ecological Risk Assessment Process for Superfund
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

Navy Ecological Risk Assessment Tiered Approach

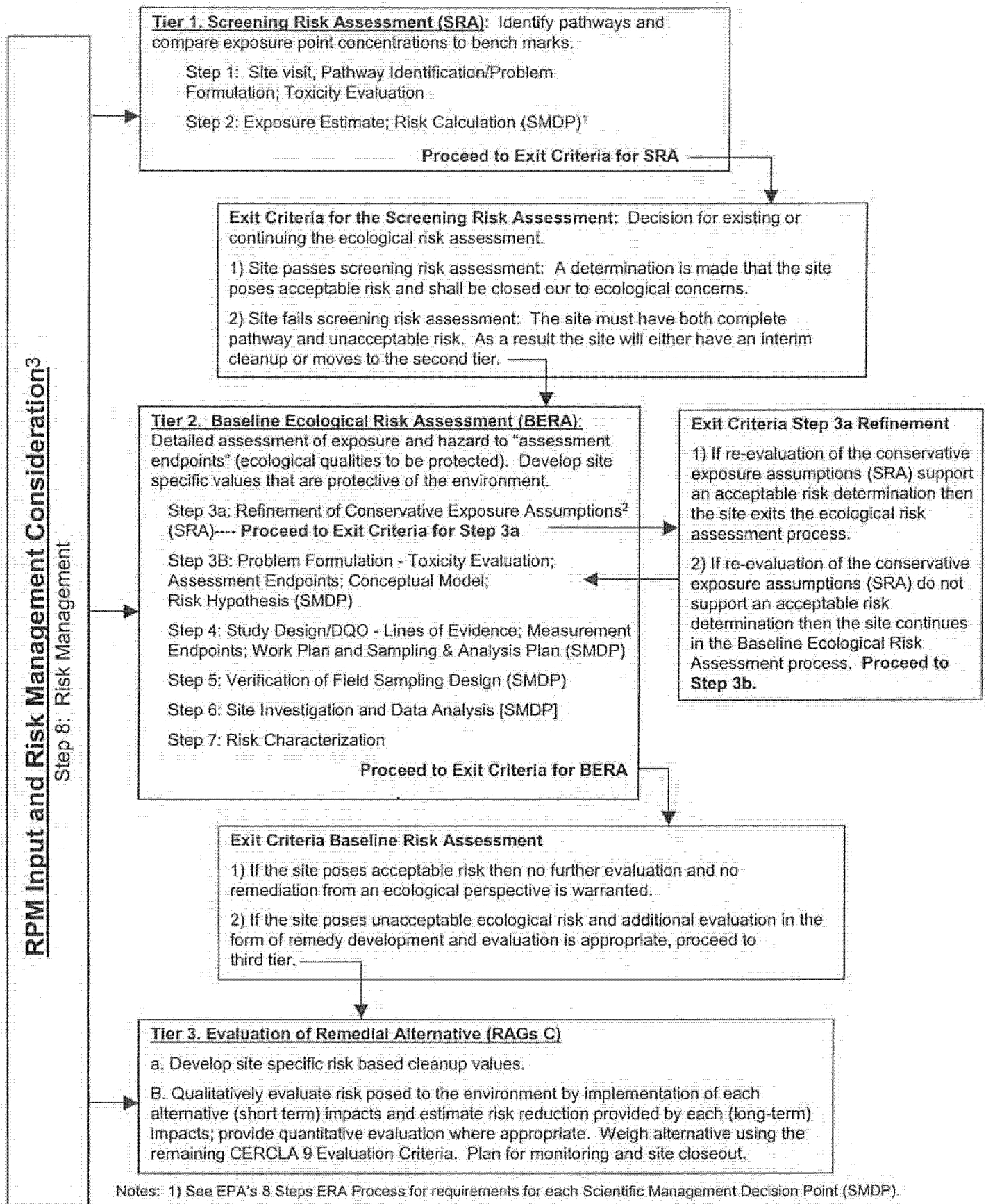


Figure 7-2
U.S. Navy Ecological Risk Assessment Tiered Approach
EJFDF Phase II RI
Pearl Harbor, Oahu, Hawaii

7.1 SUPPLEMENTAL TIER 1 – SCREENING ERA FOR THE DOWNGRADIANT OFFSITE AREA

New information collected in the offsite area in this Phase II RI was screened using the Navy Tier 1 methodology. The results of the Phase II RI SERA were evaluated further in the context of the Phase I RI results, where the refined understanding of offsite exposure was incorporated into the results of the on-site investigation.

7.1.1 Screening-Level Problem Formulation

Step 1 is divided into several parts that help define the problem at the screening level.

7.1.1.1 ECOLOGICAL SETTING

During the site reconnaissance conducted during 8–10 June 1998, vegetative communities were characterized, lists of plants and animals present (or likely to be present) in the area were prepared, and flow patterns of surface water through the wetland complex were mapped (see Figure 3-1). The ecological setting is more completely described in Section 3; biological resources and species and habitats of special concern are presented in Section 3.3.

Onsite and offsite vegetative communities can clearly be distinguished:

Onsite Vegetation. The site supports a vegetation community described as coastal dry koa haole shrubland with dry mixed vegetation. Impenetrable thickets of the invasive shrub koa haole (*Leucaena leucocephala*) cover most of the site. The principle scrub understory species is California grass (*Brachiaria mutica*). Tree kiawe (*Prosopis pallida*) occurs at higher elevations near the UST locations, and the area around the main fuel drumming facilities is dominated by California grass, swollen fingergrass (*Chloris barbata*), sourgrass (*Digitaria insularis*), partridge pea (*Chamaecrista nictitans*), Chinese violet (*Asystasia gangetica*), 'uhaloa (*Waltheria indica*), golden crown-beard (*Verbesina encelioides*), and Mexican creeper (*Antigonon leptopus*).

Offsite Vegetation. The ecological survey for the 1998 Phase II RI concentrated on the agricultural/wetlands complex downgradient of the EJFDF. The following offsite plant communities were identified during the survey:

- Coastal dry koa haole shrub
- Disturbed emergent wetland
- Littoral mangrove swamp
- Agricultural wetlands
- Ruderal plant community

Coastal Dry Koa Haole Shrub. An upland area directly south of the EJFDF site between the renovated stormwater management pond and the Sasaki farm has developed a vegetative community similar to that found on the EJFDF site. Small portions of this area have been cleared for upland farming.

Disturbed Emergent Wetland. The former marshland and adjacent uplands have been dramatically altered by excavation of ponds and drainage ditches and construction of flooded watercress fields. The dominant vegetation in the wetlands is torpedo grass (*Panicum repens*), Bermuda grass (*Cynodon dactylon*), and California grass (*Brachiaria mutica*) with vegetation such as cattails (*Typha*

angustata), parrot's feather (*Myriophyllum brasiliense*), water lilies (*Nymphaea* sp.) dominating the ponds.

Littoral Mangrove Swamp. The shore of Middle Loch in the western part of the investigation area is a gravel beach with scattered littoral vegetation, dominated by mangrove (*Rhizophora apiculata*) in the zone of normal tidal influence and milo (*Thespesia populnea*) at elevations above the mangroves.

Agricultural Wetlands. The agricultural wetlands were developed by excavating areas formerly occupied by natural wetlands. Higher value crops such as taro (*Colocasia esculenta*) and watercress (*Nasturtium microphyllum*) replaced rice as the primary crop when inexpensive rice became available from California. Currently, the major crop is watercress, which is grown in leveled, diked paddies. The paddies are flooded by continual flow from artesian wells screened within the confined basal aquifer. Water from the wells flows through the paddies and drains into a tidal ditch connected to Pearl Harbor.

Ruderal Plant Community. Several areas have been cleared for roadways, farmyards, and general access. A mixture of early successional grasses and weedy species has invaded these sites to varying degrees. Ornamental trees and shrubs are planted near both occupied and unoccupied residences.

7.1.1.2 IDENTIFICATION OF COPECS

Chemicals of potential ecological concern (COPECS) for this Tier 1 SERA were selected from chemicals detected in offsite surface soil (0–6 inches bgs), surface water, and sediment (surface media). Surface media samples were collected and analyzed for lead and organic chemicals because the site was a fuel facility where leaded gasoline was stored and transferred to drums. Validated data were used to identify COPECS.

Total petroleum hydrocarbons (TPH)-gasoline range and TPH-diesel range data were collected but not included in the evaluation. However, potentially toxic hydrocarbons, such as BTEX and PAHs, were included in the evaluation. Soil data were segregated into surface soil data (0–6 inches bgs) and subsurface soil data (> 6 inches bgs). Subsurface soil data greater than 6 inches bgs were not used in the SERA because deeper soils are anoxic and most plant roots and benthic invertebrates do not penetrate below this depth. Subsurface soil analytical results were not used in the SERA. Sediment and surface water were also sampled and analyzed for lead and organic contaminants.

All analytical data were validated as described in Section 4.5. Any valid chemical detected at a sampling location within an ecologically significant portion of an environmental medium (i.e., surface soil, sediment, or surface water at depths of 6 inches or less) was considered a preliminary COPEC for that sampling location. Several mercury data were rejected because of matrix interference.

COPECS carried through the SERA are listed in Table 7-1.

Table 7-1: COPECs in Surface Soil, Sediment, and Surface Water

Surface Soil COPECs	Sediment COPECs	Surface Water COPECs
Inorganics		
Lead	Lead	Lead
Organics		
Anthracene	Acetone	Benzo(a)anthracene
Benzo(a)anthracene	Anthracene	Benzo(a)pyrene
Benzo(a)pyrene	Benzo(a)anthracene	Benzo(b)fluoranthene
Benzo(b)fluoranthene	Benzo(a)pyrene	Benzo(g,h,i)perylene
Benzo(g,h,i)perylene	Benzo(b)fluoranthene	Benzo(k)fluoranthene
Benzo(k)fluoranthene	Benzo(g,h,i)perylene	BEHP
BEHP	Benzo(k)fluoranthene	Butylbenzylphthalate
Chrysene	BEHP	Chrysene
Dibenzo(a,h)anthracene	4-Bromophenyl-phenylether	Dibenzo(a,h)anthracene
Fluoranthene	2-Butanone	Di-n-octylphthalate
Indeno(1,2,3-cd)pyrene	Carbon disulfide	Fluoranthene
Phenanthrene	Chrysene	Indeno(1,2,3-cd)pyrene
Pyrene	Dibenzo(a,h)anthracene	2-Nitrophenol
	Diethylphthalate	Phenanthrene
	Fluoranthene	Pyrene
	Indeno(1,2,3-cd)pyrene	
	Phenanthrene	
	Phenol	
	Pyrene	

7.1.1.3 ASSESSMENT ENDPOINTS

According to EPA (1997a) guidance, assessment endpoints for a SERA are any adverse effects on ecological receptors. Ecological receptors are defined as plant and animal populations, communities, habitats, or sensitive environments. The specific assessment endpoints for this SERA include the following:

- Protection of benthic invertebrates as a food source for local fish and wildlife
- Protection and maintenance (survival, growth, and reproduction) of aquatic life (i.e., fish, tadpoles, aquatic invertebrates)
- Protection and maintenance (survival, growth, and reproduction) of local omnivorous birds
- Protection and maintenance (survival, growth, and reproduction) of local omnivorous mammals
- Protection of individual threatened and endangered species (black-necked stilt)

With the exception of the endangered species endpoint, the endpoints listed above are population-level endpoints (as opposed to community- or ecosystem-level assessment endpoints). Endangered species are protected as individuals. Note that changes in abundance of ecologically significant species at the population level will undoubtedly have effects at higher organizational levels. Therefore, these assessments endpoints should be a good indicator of overall ecological health or harm.

7.1.1.4 MEASUREMENT ENDPOINTS

Measurement endpoints provide the actual measurements used to evaluate ecological risk; they are selected to represent mechanisms of toxicity and exposure pathways related to representative species. Measurement endpoints were identified as adverse effects on the survival, reproduction, or development of a representative species (or its surrogate) caused by exposure to COPECs. Measurement endpoints generally include measured or modeled concentrations of chemicals in water, sediment, soil, fish, birds, and/or mammals; laboratory toxicity studies; and field observations. Any adverse physiological effect on a plant species was considered in choosing a plant endpoint. Reproductive effects on plants were not the only measure; many physiological effects in plants (e.g., chlorosis) may cause a reduction in habitat value for animal species and thus cause adverse ecological effects.

The measurement endpoints identified for this SERA are as follows:

- Exceedance of guidelines for concentrations of COPECs in surface water that are protective of aquatic life as defined by the EPA Office of Water
- Exceedance of guidelines for concentrations of COPECs in sediments that are protective of benthic organisms as defined in the National Oceanic and Atmospheric Administration (NOAA) Status and Trends Program
- Measured or modeled COPEC chronic intake concentrations or body burdens in representative species to determine exceedance of effect-level thresholds based on TRVs

Final assessment and measurement endpoints are summarized in Table 7-2.

7.1.1.5 REPRESENTATIVE SPECIES

Many species have been identified from the EJFDF and the adjoining offsite wetland/agricultural area. Several species were selected to represent the entire flora and fauna of the area. In selecting representative species, the following ecological and species characteristics that influence exposure were considered:

- **Ecological Importance.** This includes those species that affect the structure and function of existing habitats, communities, or ecosystems (e.g., key members of the local food web). The representative species should be major intermediate components in the food web: if a population of a pivotal species is disrupted, there could be consequences throughout the food web, resulting in an ecosystem balance disruption.
- **Body Size.** Species of small body size are preferred, because they are likely to be more affected by a given exposure. Due to their higher metabolic demands, small species tend to eat more food per unit body weight per day than do larger animals.
- **Site-Use Area.** Species with small foraging areas or home ranges are likely to be affected by contamination at a site more than species with large foraging areas because a higher percentage of foraging may occur in contaminated areas.

Table 7-2: Assessment Endpoints for Ecological Risk Assessment

Receptor of Concern	Exposure Pathway	Assessment Endpoint*	Testable Hypothesis	Measurement Endpoint	Data Available
Aquatic and terrestrial plants (watercress and koa haole)	Root uptake of chemicals from surface soil or sediment	Decline in growth or yield of plants	H _a : The concentration of chemicals of potential concern in the surface soil or sediment exceeds a level known to be toxic to plants.	Compare chemical concentrations in surface soil or sediment at potentially impacted locations to toxicity benchmarks developed from literature.	Site-specific surface soil chemical data from potentially impacted locations and reference locations
Freshwater and saltwater aquatic life and sediment-dwelling organisms (fish, tadpoles, crayfish, snails, and shrimp)	Uptake of chemicals from water and sediment	Decline in growth, reproduction, or activity of aquatic and benthic organisms	H _a : The concentration of chemicals of potential concern in the surface water or sediment exceeds a level known to be toxic to aquatic or benthic organisms	Compare chemical concentrations in surface water at potentially impacted locations to chronic WQSS. Compare chemical concentrations in sediment at potentially impacted locations to sediment threshold effect levels. Compare chemical concentrations in aquatic organisms (estimated by modeling) to toxicity benchmarks developed from literature.	Site-specific surface water chemical data from potentially impacted locations, and site-specific sediment chemical data from potentially impacted locations
Small omnivorous mammals (house mouse)	Ingestion of chemicals accumulated in vegetation and soil invertebrates and from soil	Decline in mouse populations	H _a : The ingestion of bioaccumulative chemicals from earthworms and surface soil exceeds a level known to be toxic to mice.	Compare dose of bioaccumulative chemicals from ingestion of vegetation, soil invertebrates, and soil (estimated by modeling) to toxicity benchmarks developed from literature.	Site-specific surface soil chemical data from potentially impacted locations
Small omnivorous birds (northern cardinal and black-necked stilt)	Ingestion of chemicals accumulated in plants and soil or sediment invertebrates, and from soil or sediment	Decline in local bird populations	H _a : The ingestion of bioaccumulative chemicals from earthworms, plants, and surface soil, or aquatic organisms, plants, and sediment exceeds a level known to be toxic to birds.	Compare dose of bioaccumulative chemicals from ingestion of plant material and invertebrates and soil (estimated by modeling) to toxicity benchmarks developed from literature.	Site-specific surface soil chemical data from potentially impacted locations
Endangered wading birds feeding in the watercress fields (black-necked stilt)	Ingestion of chemicals accumulated in plants, sediment invertebrates, and from incidental sediment ingestion	Loss of individuals and decline in local populations of endangered water birds	H _a : The ingestion of bioaccumulative chemicals from plants, aquatic organisms, and sediment exceeds a level known to be toxic to birds.	Compare dose of bioaccumulative chemicals from ingestion of plant material and invertebrates and soil (estimated by modeling) to toxicity benchmarks developed from literature.	Site-specific sediment and water chemical data from potentially impacted locations

H_a = alternative hypothesis

* Assessment endpoints identified for evaluation in this SERA are based on the parameters used to derive toxicity benchmarks (see Measurement Endpoint column), and are not intended to imply measurement of these parameters in the field.

- **Feeding Guild.** Certain methods of finding, processing, and consuming food present a higher risk of exposure than do others. For example, the downy woodpecker forages beneath bark on standing trees, whereas the rufous-sided towhee forages on the ground, where it is more likely to contact soil contaminants.
- **Diet.** Species with a specialized diet are likely to be more affected by a given contaminant exposure pathway and by changes in food species density because they have fewer food alternatives.
- **Fecundity.** Species having small litter or egg clutch sizes and fewer litters or clutches per year are likely to be impacted by adverse effects on reproductive success more than species that produce large numbers of offspring.
- **Resident or Nesting Species.** Resident or nesting species may spend more time in the contaminated area per year than non-resident species. Therefore, resident species are more likely to be affected by contamination at the site.

After consideration of all of the exposure-related factors and species identified at the site, two plant and three animal species were selected as representative terrestrial species of concern (see Table 7-3). Selection was based largely on the ecological importance of the species and their potential for exposure to site surface soil and sediment contamination. It is assumed that the assessment of risk to these maximally exposed species will represent risk to the entire ecosystem, thus protecting all species subject to lower exposures.

Table 7-3: Summary of Potential Representative Species

Common Name	Scientific Name	Justification (Critical Ecosystem Role)
Plants		
Koa haole	<i>Leucaena leucocephala</i>	Food and shelter
Watercress	<i>Nasturtium microphyllum</i>	Food chain species
Animals		
House mouse	<i>Mus musculus</i>	Herbivorous prey
Northern cardinal	<i>Cardinalis cardinalis</i>	Omnivore
Black-necked stilt	<i>Himantopus mexicanus knudseni</i>	Predator with some plants
Aquatic and benthic life (various)	n/a	Food chain species
n/a	not applicable	

These species were selected for the following reasons:

- **Koa haole tree (*Leucaena leucocephala*)** provides cover and food for small upland mammals and granivorous birds.
- **Watercress (*Nasturtium microphyllum*)** provides food for humans, herbivorous small mammals, and omnivorous birds of the wetlands.
- The **house mouse (*Mus musculus*)** is one of the smallest herbivores commonly found in areas with suitable habitat within the site. It is also a common prey species for nocturnal and crepuscular predators that may hunt at the facility. House mice are active year-round and may forage on the grassy areas, where they are exposed to surface soil. An ecological profile of this species is presented in Appendix O.2. House mice are considered similar to deer mice in foraging habits, eating both seeds and invertebrates, with approximately 2 percent of their daily oral intake as soil (EPA 1993b). The majority of free-water needs are met through food

intake. House mice are small (11–22 grams; Burt and Grossenheider 1980), resident rodents with a small home range assumed to be similar to that of deer mice (0.058–0.062 hectare; Wolff 1985). This allows for an assumption of maximal exposure to COPECs at each site.

- The **northern cardinal** (*Cardinalis cardinalis*) is a small-sized (45 grams) bird commonly found at the site. Its diet comprises a majority of plant material and a minority of animal material. This omnivorous feeding habit allows it to represent both herbivore and predator exposure pathways in the exposure model. An ecological profile with further life history data for the northern cardinal is presented in Appendix O.2.
- The **black-necked stilt** (*Himantopus mexicanus knudseni*) is a medium-sized (200 grams) wading bird found near the site. It is listed as endangered by both the State of Hawaii and the U.S. Fish and Wildlife Service (USFWS). Its diet consists almost entirely of animal material (e.g., aquatic organisms, worms, and snails), with a minimum of vegetable matter. This carnivorous feeding habit allows it to represent a predator exposure pathway. An ecological profile with further life history data for the black-necked stilt is presented in Appendix O.2.
- **Freshwater aquatic life**, as defined by EPA Office of Water for the development of ambient water quality criteria, were selected for assessing risk from potentially contaminated surface water in the wetlands. The **benthic community**, as defined by NOAA in their Status and Trends Program, was selected as the assessment endpoint for contaminated sediment.

7.1.2 Exposure Pathway Analysis

Exposure pathways differ in importance from species to species and from site to site. For example, sites with minimum habitat value may be used by a large number of ecologically significant species that tolerate human disturbance of natural habitats. The representative species selected for assessment endpoints (koa haole, watercress, house mouse, northern cardinal, and black-necked stilt) reflect the varied habitats at the site.

The major terrestrial pathways chosen for analysis in this ecological risk assessment are as follows:

- Uptake of COPECs from surface soil by vegetation (koa haole)
- Ingestion of contaminated soil by animals (house mouse and cardinal)
- Ingestion of contaminated plants by animals (house mouse and cardinal)
- Ingestion of contaminated soil invertebrates by predators (house mouse and cardinal)

The major wetland pathways chosen for analysis in this ecological risk assessment are as follows:

- Uptake of COPECs from surface sediment by vegetation (watercress)
- Uptake of COPECs from surface water by aquatic organisms
- Uptake of COPECs from sediment by benthic organisms
- Ingestion of contaminated sediment by individual black-necked stilts
- Ingestion of contaminated plants by individual black-necked stilts
- Ingestion of contaminated aquatic organisms by individual black-necked stilts

The primary exposure pathways for both plant and animal receptors are associated with contaminated soil in the upland areas, and with contaminated surface water and sediment in the wetland areas. The other major exposure pathway is ingestion of contaminated food by animals.

Exposure pathways that were not considered in this SERA include plant absorption of air contaminants, inhalation of contaminated dust by animals, and dermal absorption of contaminants from soil by animals other than the earthworm. These routes lack sufficient scientific data for evaluation, and they are assumed to minimally contribute to the overall exposure of ecological receptors to soil contaminants compared to the pathways chosen for evaluation. Exposure pathways are listed in Table 7-4.

Table 7-4: Potential Offsite Exposure Pathways for Offsite Ecological Receptors

Potential Receptors	Exposure Route	Pathway(s) Selected for Evaluation?	Comments
Air			
Terrestrial wildlife	Inhalation	No	Incomplete because site is covered with vegetation, or vegetated wetlands; wind-borne particulate emission is unlikely. Volatile organic compounds are not COPECs.
Surface Water			
Aquatic organisms	Direct contact with integument and gills and ingestion of water (uptake)	Yes	Pathway potentially complete; selected for quantitative evaluation.
Aquatic birds	Intentional or accidental ingestion	Yes	Pathway potentially complete; selected for quantitative evaluation.
Sediment			
Aquatic plants	Direct contact (root uptake)	Yes	Pathway potentially complete; selected for quantitative evaluation.
Benthic organisms	Direct contact with integument and gills and ingestion of sediment (uptake)	Yes	Pathway potentially complete; selected for quantitative evaluation.
Surface Soil			
Terrestrial plants	Direct contact (root uptake)	Yes	Pathway potentially complete; selected for quantitative evaluation.
	Direct contact (foliar uptake)	No	Not evaluated because applicable exposure and toxicity data could not be found in the scientific literature for the majority of COPECs.
Terrestrial invertebrates (e.g., earthworms)	Ingestion and direct contact (dermal absorption)	Yes	Soil invertebrates are considered as a source of food chain exposure; selected for quantitative evaluation as a food item.
Terrestrial wildlife (e.g., mammals, birds)	Ingestion	Yes	Pathway potentially complete; selected for quantitative evaluation.
	Direct contact (dermal absorption)	No	Not evaluated because applicable exposure data could not be found in the scientific literature, and exposure is expected to be minimal.
Food			
Terrestrial wildlife (e.g., mammals, birds)	Ingestion	Yes	Pathway potentially complete; selected for quantitative evaluation.

Uptake of COPECs in Surface Water by Aquatic Organisms: *Water to Animal*. Aquatic organisms such as fish, tadpoles, shrimp, and crayfish can take up contaminants from water through the integument and gill surface. They also may drink contaminated water. The two methods of

exposure cannot be separated. Therefore, the combined accumulation of body burden is attributed to "uptake."

Intake of COPECs in Surface Water by Aquatic Birds: *Water to Animal*. Ingestion of surface water by the black-necked stilt may occur intentionally or accidentally when eating food.

Intake of COPECs in Surface Water Resulting from Consumption of Aquatic Life by Aquatic Birds: *Water to Aquatic Invertebrates to Black-Necked Stilt*. Animals such as the black-necked stilt may consume aquatic organisms such as shrimp, tadpoles, or insects (which take up contaminants from surface water) as a significant part of their diet.

Uptake of COPECs in Sediment by Benthic Organisms: *Sediment to Animal*. Benthic organisms such as snails can take up contaminants from sediment through the integument. They also may ingest sediment and detritus to extract its organic content. The two methods of exposure cannot be separated. Therefore, the combined accumulation of body burden is attributed to "uptake."

Uptake of COPECs in Sediment by Plants: *Sediment to Plant*. A major route of exposure to sediment contaminants in aquatic plants is via plant root uptake. Watercress may be exposed via this route.

Uptake of COPECs in Soil by Plants: *Soil to Plant*. The major route of exposure to soil contaminants in plants is via plant root uptake. Approximately 99 percent of the root system of most plants occurs in the top 2 feet of soil, and almost all nutrient and contaminant uptake occurs in the top 3 feet of soil (Perry 1984). Most of the absorptive surface of roots (root hairs) is found near the ground surface. This is especially true of wetland species, which are shallow rooted to avoid anoxic conditions in subsurface sediments. Koa haole and other terrestrial site species may be exposed via this pathway.

Uptake of COPECs in Soil by Invertebrates: *Soil to Animal*. Invertebrates such as earthworms can take up contaminants from moist soil through the integument. They also ingest soil to extract its organic content. The two methods of exposure cannot be separated. Therefore, the combined accumulation of body burden is attributed to "uptake." Body burden estimates for soil invertebrates are used to predict food chain exposure in worm-eating predators.

Intake of COPECs in Soil by Animals: *Soil to Animal*. Ingestion of soil by the house mouse and northern cardinal may occur accidentally when eating food, or intentionally to aid in the digestion process. Ingestion of sediment by the black-necked stilt may occur accidentally when eating food in the wetlands. The house mouse may also ingest soil when grooming its pelt (Beyer and Stafford 1993).

Intake of COPECs in Soil by Animals Resulting from Consumption of Plants: *Soil to Plant to Animal*. Animals such as the house mouse, northern cardinal, and black-necked stilt may consume vegetable matter or seeds growing in contaminated soil or sediment.

Intake of COPECs in Soil by Animals Resulting from Consumption of Invertebrates: *Soil to Earthworm to Animal*. Animals such as the house mouse and northern cardinal may consume invertebrates such as earthworms and insects (which take up contaminants from soil) as a significant part of their diet.

7.1.3 Development of Conceptual Site Model

The CSM is presented in Section 5.5. A summary diagram of the CSM as it applies to ecological receptors is presented in Figure 7-3. The CSM identifies complete pathways from offsite surface water, sediment, and soil to offsite ecological receptors. However, the Phase II RI results suggest that there is no connection between the contamination detected in offsite surface media and EJFDF operations, or the 1971 MOGAS spill (see Section 4). Other potential sources of COPECs found in the offsite area include buried petroleum pipelines along Waiawa Road and the bicycle path, dredging and filling operations in the wetlands, storage of fill material on the offsite properties, and storage of heavy equipment on offsite properties (see Sections 3.1.3 and 3.6).

Although the offsite COPECs cannot be attributed to the EJFDF facility, the new analytical data collected in the offsite area were subjected to a Tier I SERA.

7.1.4 Toxicity Evaluation

The toxicity evaluation begins with the development of toxicity reference values (TRVs). A TRV is a tissue concentration (for invertebrates and plants, in mg/kg) or dosage (for animals, in milligram per kilogram per day [mg/kg-day]) of a chemical believed to have little or no effect on the long-term health of the representative species of concern. TRVs are specific for each chemical, receptor, and exposure route (e.g., ingestion, inhalation). The TRV of a chemical is equivalent to the exposure-specific, literature-derived no-observed-adverse-effect level (NOAEL) of that chemical for particular plant or animal species of concern. Two types of TRVs were used in this SERA: critical-dose TRVs and general TRVs, based on the source of the underlying toxicity data.

The source of "critical-dose" TRVs is a document prepared by the Navy in cooperation with the EPA Region IX Biological Technical Assistance Group (BTAG) (DON 1999). The Navy developed a series of TRVs ("low") for use in calculating screening-level risk and screening-level soil screening concentrations in soil (see Section 7.2.2) at all CLEAN II sites in California. These TRVs have been recommended for use at CLEAN II sites in Hawaii and Guam. The Navy/BTAG TRVs have been developed for the ingestion pathway for mammals and birds for a limited number of chemicals. The Navy developed the TRVs from lowest-observed-adverse-effect level (LOAEL) and NOAEL toxicity values reported in the primary literature. Only the "low" BTAG TRVs are considered critical-dose TRVs. For chemicals for which "low" Navy/BTAG TRVs were not available, "general" TRVs were developed from LOAEL and NOAEL toxicity values obtained from the primary literature, similar to the Navy/BTAG procedure.

In accordance with the measurement endpoints (see Section 7.1.1.4), peer-reviewed toxicity studies that report reproductive or developmental ingestion NOAELs for a COPEC for a representative species or surrogate were sought in developing TRVs for animals in this SERA. For plants, uptake NOAELs that cause any adverse physiological effect (e.g., growth, chlorosis, flowering) on the representative species were sought. (It is assumed that any measurable effect on a plant would have an adverse effect on its quality or quantity as a food for herbivores.)

As noted above, uncertainty factors were sometimes applied in developing TRVs because the toxicity information sought was not always available in the literature. Application of uncertainty factors to literature-derived toxicity values is called extrapolation. The two general categories of extrapolations are taxonomic extrapolation and endpoint extrapolation. Each is described below.

A compilation of uncertainty factors for each category of extrapolation is presented in Table 7-5. Note that the total numeric uncertainty used to generate each TRV is the product of the uncertainty factors from each of the extrapolations.

Pathway	Contributing Sources	Transport Mechanism	Exposure Route	Current Land Use		Future Land Use		Rationale	
				Aquatic Receptors	Terrestrial Receptors	Aquatic Receptors	Terrestrial Receptors		
Contaminant Source: Offsite Contaminant Sources Not Associated with the 1971 MOGAS Release									
Surface Water	Offsite Surface Soil/Sediment	Overland Flow to Watershed Fields	Incidental Ingestion of Surface Water	Complete	Insignificant	Insignificant	Insignificant	Aquatic organisms may ingest dissolved contaminants from water, but it is combined with dermal uptake for a combined load.	
			Dermal Contact with Surface Water	Complete	Insignificant	Complete	Insignificant	Aquatic organisms may take up dissolved contaminants from water through the gills or integument. Exposure time for terrestrial organisms is too brief to be significant.	
			Inhalation of VOCs from Surface Water	Incomplete	Incomplete	Incomplete	Incomplete	The pathway is incomplete because VOCs were not detected in surface water.	
			Ingestion of Plants/Animals (food chain)	Complete	Complete	Complete	Complete	Aquatic food chains can lead to wading birds such as the stil.	
			Overland Flow to Pearl Harbor/Middle Loch	Incidental Ingestion of Surface Water	Complete	Complete	Complete	Complete	The potential effect of contaminant discharge to Pearl Harbor is the subject of a separate investigation, as discussed in Section 5.5.4.
				Dermal Contact with Surface Water	Complete	Insignificant	Complete	Incomplete	
				Inhalation of VOCs from Surface Water	Incomplete	Incomplete	Incomplete	Incomplete	The pathway is incomplete because VOCs were not detected in surface water.
				Ingestion of Aquatic Organisms (food chain)	Complete	Complete	Complete	Complete	The potential effect of contaminant discharge to Pearl Harbor is the subject of a separate investigation, as discussed in Section 5.5.4.
Air	Offsite Soil/Sediment	Wind-borne Particulates	Inhalation of Fugitive Particulates	Insignificant	Insignificant	Insignificant	Insignificant	The pathway is complete for terrestrial receptors, but is insignificant compared to ingestion pathways. It is also considered insignificant because of relatively high soil moisture content and low concentrations of VOCs in soil.	
			Volatilization	Inhalation of VOCs	Insignificant	Insignificant	Insignificant		Insignificant
		Direct Contact	Incidental Ingestion of Soil/Sediment	Complete for Sediment	Complete for Soil and Sediment	Complete for Sediment	Complete for Soil and Sediment		Terrestrial species may ingest contaminated soil incidental to feeding. Wading birds such as the stil may ingest sediment incidental to feeding in shallow water.
			Dermal Contact with Soil/Sediment	Complete for Benthic Organisms	Insignificant	Complete for Benthic Organisms	Insignificant		Uptake of contaminants from pore water of sediment by benthic invertebrates is complete. Dermal absorption of contaminants by terrestrial receptors is considered insignificant compared to ingestion pathways.

Figure 7-3
Conceptual Site Model for Ecological Receptors
Phase II RI
Ewa Junction Fuel Drumming Facility
Pearl Harbor, Oahu, Hawaii

Table 7-5: Uncertainty Factors Used for Taxonomic, Endpoint, and Chemical Extrapolations

Description			Uncertainty Factor
Relation of Test Species to Species of Concern			
Animal ^a	different species within a genus		1
	different genera within a family		1
	different classes within a phylum		10
Plant ^b	both monocotyledonous		1
	both dicotyledonous		1
	test species dicot, species of concern monocot		1
	test species monocot and species of concern dicot		10
NOAEL			1
NOAEL _{acute}	to	NOAEL _{chronic}	2
LOAEL _{acute}	to	NOAEL _{chronic}	10 ^a

NOAEL_{acute} = acute no-observed-adverse-effect level

LOAEL_{chronic} = chronic lowest-observed-adverse-effect level

LOAEL_{acute} = acute lowest-observed-adverse-effect level

^a Source: California DTSC (1996).

^b Exposures of less than 14 days were considered acute, while exposures of 14 days or greater were considered chronic. One exception concerns animal developmental studies; any exposure greater than a single dose during gestation was considered chronic.

7.1.4.1 TAXONOMIC EXTRAPOLATION

Taxonomic extrapolation assumes that toxicological effects reported for one species can be used to predict the toxicological effects in a taxonomically related species. These assumptions have proven valid in extrapolations used to estimate toxicity in aquatic species (EPA 1989b). Although little is known about extrapolations to assess risk to terrestrial plant and animal species, the paucity of specific toxicity data mandates such extrapolations. As an example of the use of taxonomic extrapolation, an uncertainty factor of 10 is assigned to toxicity data derived from laboratory rats if the species of concern is a bird (EPA 1997a).

7.1.4.2 ENDPOINT EXTRAPOLATION

Endpoint extrapolation converts toxicological data that are not expressed as chronic NOAEL (NOAEL_{chronic}) or chronic no-observed-effect concentration (NOEC_{chronic}) values to such values. Examples of other of toxicological endpoints include the following:

- Lowest-observed-adverse effect level (LOAEL)

The California Department of Toxic Substances Control provides guidance for applying uncertainty factors for extrapolation from some endpoints to a NOAEL_{chronic} (California DTSC 1996). Although the document distinguishes between acute and chronic toxicological studies, it does not define these terms, nor does it provide guidance for how to apply uncertainty factors to studies that do not fit clearly into either category (e.g., subacute or subchronic). For toxicological studies on mammals, Klaassen and Eaton (1991) note that subacute studies typically include up to 14 days' exposure. For the purpose of this risk assessment, exposure times of less than 14 days are considered acute; exposures of 14 days or longer are considered chronic.

7.1.4.3 CALCULATION OF DAILY DOSES FROM FEEDING STUDIES

In some cases, development of avian TRVs from data in the primary literature required additional calculations. This is because many of the studies on avian species report dosages in units of milligram of chemical per kilogram of food (fresh weight). A conversion was necessary to generate dosages in units of milligram of chemical per kilogram of animal body weight per day (mg/kg-day), the standard exposure unit used in this SERA. This conversion required knowledge of the daily food intake rate, the percent moisture in the diet, and average weight of each test species. Conversions could then be calculated as shown below (based on Opresko, Sample, and Suter 1996):

$$\begin{aligned} & \text{Intake dosage} \times \frac{1}{1 - \text{moisture content}} \times \text{ingestion rate} \times \frac{1}{\text{body weight}} \\ &= \frac{\text{mg chemical}}{\text{kg food [fresh]}} \times \frac{\text{kg food [fresh]}}{\text{kg food [dry]}} \times \frac{\text{kg food [dry]}}{\text{day}} \times \frac{1}{\text{kg body weight}} \\ &= \text{mg chemical} \times (\text{kg body weight} \times \text{day})^{-1} \end{aligned}$$

Ingestion rates, moisture contents in the diet, and body weights of the avian test species used in the studies from which avian TRVs were derived using this conversion are presented in Table 7-6.

Table 7-6: Ingestion Rates, Diet Moisture Contents, and Body Weights of Avian Test Species

Avian Test Species	Exposure Factor	Value	Reference
Mallard	Ingestion rate ^a	0.0592 kg food (dry)/day	EPA (1993b)
	Moisture content in diet	0.07 kg water/kg food (fresh)	Heinz, Hoffman, and Gold (1988)
	Body weight ^b	1.134 kg	Nelson and Martin (1953)
Ringed dove	Ingestion rate ^a	0.0124 kg food (dry)/day	EPA (1993b)
	Moisture content in diet	0.1 kg water/kg food (fresh)	EPA (1993b)
	Body weight ^b	0.141 kg	Dunning (1993)
Japanese quail	Ingestion rate ^a	0.0122 kg food (dry)/day	EPA (1993b)
	Moisture content in diet	0.1 kg water/kg food (fresh)	EPA (1993b)
	Body weight ^b	0.157 kg	Edens and Garlich (1983)

^a Calculated using allometric equations for non-passerine birds.

^b Body weights given are the midpoint of a range or the average male and female body weights.

Critical-dose TRVs for ecological receptors and exposure pathways (i.e., uptake or ingestion) relevant to this SERA are presented in Appendix O.1. Also presented in this appendix are summary data from peer-reviewed literature used to generate TRVs that were not obtained directly from the Navy/BTAG document.

Hawaii DOH chronic WQSs and NRWQC (EPA 1999b) for the protection of aquatic life were used as primary criteria to screen surface water COPEC concentrations. If neither state nor federal criteria were available, Great Lakes Tier 2 values presented in Suter and Tsao (1996) were used as tertiary screening values.

Sediment TELs proposed by Smith et al. (1996) were used to screen COPEC concentrations in freshwater sediments (watercress fields). Effects range-low (ER-L) values were used to screen marine sediment COPECs (shoreline and tidal drainage ditch). Long et al. (1995) proposed ER-Ls

for screening marine and estuarine sediments under NOAA's Status and Trends Program. Screening of these sample results is described in Section 4.1.2.

The final TRVs used in this SERA are summarized in Table 7-7.

Table 7-7: Summary of Toxicity Reference Values Used to Screen Risk to Terrestrial Vertebrates

COPEC	Final TRVs (mg/kg-day)		
	House Mouse	Northern Cardinal	Black-Necked Stilt
Inorganic			
Lead	3.92E-03	1.4E-02	1.4E-02
PAH Group 1			
Anthracene	1.21E+02	2.25E+01	2.25E+01
Benzo(g,h,i)perylene	1.21E+02	2.25E+01	2.25E+01
Fluoranthene	1.21E+02	2.25E+01	2.25E+01
Phenanthrene	1.21E+02	2.25E+01	2.25E+01
Pyrene	1.21E+02	2.25E+01	2.25E+01
PAH Group 2			
Benzo(a)anthracene	1.51E+00	2.25E+00	2.25E+00
Benzo(a)pyrene	1.51E+00	2.25E+00	2.25E+00
Benzo(b)fluoranthene	1.51E+00	2.25E+00	2.25E+00
Benzo(k)fluoranthene	1.51E+00	2.25E+00	2.25E+00
Chrysene	1.51E+00	2.25E+00	2.25E+00
Dibenzo(a,h)anthracene	1.51E+00	2.25E+00	2.25E+00
Indeno(1,2,3-cd)pyrene	1.51E+00	2.25E+00	2.25E+00
Misc. Organic			
Acetone	2.61E+02	1.70E+02	1.70E+02
2-Butanone	4.52E+02	1.73E+01	1.73E+01
2-Nitrophenol	n/a	n/a	n/a
4-Bromophenyl-phenylether	n/a	n/a	n/a
Carbon disulfide	3.29E+02	1.26E+01	1.26E+02
Phenol	1.88E+03	7.21E+01	5.00E+00
Phthalate Esters			
BEHP	5.22E+01	1.10E+00	1.10E+00
Butylbenzylphthalate	5.22E+01	1.10E+00	1.10E+00
Diethylphthalate	5.28E+03	1.63E+02	1.63E+02
Di-n-butylphthalate	6.34E+02	1.10E-01	1.10E-01

n/a = not applicable for this species in this medium

7.2 TIER 1, STEP 2 – EXPOSURE ESTIMATION AND RISK CALCULATION

7.2.1 Exposure Estimation

In calculating exposure, EPCs, species-specific and chemical-specific exposure parameters and exposure equations are considered.

7.2.1.1 EXPOSURE POINT CONCENTRATIONS

Table 7-8 presents surface soil concentrations of COPECs used to estimate uptake values (for plants) and intake values (for animal receptors) at each site with complete exposure pathways. In Step 2 of this SERA, the maximum values were used as the EPCs. Analytical data for surface soil (0–6 inches), subsurface soil (> 6 inches), and wetland surface water and sediments are presented in Appendix N, Table N-1.

Table 7-8: Maximum EPCs for COPECs in the EJFDF Offsite Area

Chemical Name	Surface Soil (mg/kg)	Surface Water (µg/L)	Freshwater Sediment (mg/kg)	Marine Sediment (mg/kg)
Inorganic				
Lead	44.32	97.60	42.39	56.14
PAH Group 1				
Anthracene	0.003	NC	0.012	NC
Benzo(g,h,i)perylene	0.035	11	0.070	0.116
Fluoranthene	0.032	33	0.084	0.024
Phenanthrene	0.014	16	0.021	0.026
Pyrene	0.032	27	0.066	0.067
PAH Group 2				
Benzo(a)anthracene	0.021	11	0.042	0.023
Benzo(a)pyrene	0.016	11	0.050	0.019
Benzo(b)fluoranthene	0.032	12	0.082	0.047
Benzo(k)fluoranthene	0.020	12	0.066	0.012
Chrysene	0.027	15	0.070	0.030
Dibenzo(a,h)anthracene	0.016	0.337	0.021	0.021
Indeno(1,2,3-cd)pyrene	0.018	12	0.079	0.028
Misc. Organic				
Acetone	NC	NC	0.060	0.075
4-Bromophenyl-phenylether	NC	NC	0.197	0.197
2-Butanone	NC	NC	0.026	0.074
Carbon disulfide	NC	NC	0.008	0.008
2-Nitrophenol	NC	2.35	NC	NC
Phenol	NC	NC	0.061	0.038
Phthalate Esters				
BEHP	0.060	0.410	0.042	0.073
Diethylphthalate	NC	NC	0.041	0.041
Di-n-octylphthalate	NC	.865	NC	NC

NC = not a COPEC in this medium

7.2.1.2 SPECIES-SPECIFIC EXPOSURE PARAMETERS

Factors used to estimate COPEC intake concentration values for ecological animal receptors are referred to as exposure parameters. Such factors as species morphology, physiology, and behavior influence how individuals are exposed to COPECs and how much of a given COPEC in a given

medium is taken in by individual representative species. The species-specific exposure factors discussed in this section are summarized in Table 7-9.

Table 7-9: Animal Species-Specific Exposure Factors

Factor	Value	Reference
HOUSE MOUSE		
Mean body weight (BW) (kg)	0.0196	Derived from Schlesinger and Potter (1974)
Minimum body weight (BW) (kg)	0.018	Derived from Schlesinger and Potter (1974)
Mean foraging area (ha)	0.06	Derived from Wolff (1985)
Mean food intake (mg/day, dry weight)	3,326 ^a	Derived from Cronin and Bradley (1988)
Maximum food intake (mg/day, dry weight) (FI)	3,550 ^a	Derived from Cronin and Bradley (1988)
Water intake (mL/day)	2.90 ^b	EPA (1993b)
Diet partition factor	0.02 (soil) (SI) 0.75 (plant) (PI) 0.25 (animal) (AI)	Whitaker (1966); EPA (1993b)
NORTHERN CARDINAL		
Mean body weight (BW) (kg)	0.0447	Collins and Boyajian (1965)
Minimum body weight (BW) (kg)	0.0394	Collins and Boyajian (1965)
Mean foraging area (ha)	0.91	Schoener (1968)
Mean food intake (mg/day, dry weight) (FI)	10,061 ^a	EPA (1993b)
Maximum food intake (mg/day, dry weight) (FI)	11,066 ^a	EPA (1993b)
Water intake (mL/day)	7.4 ^b	EPA (1993b)
Diet partition factor	0.03 (soil) (SI) 0.71 (plant) (PI) 0.29 (animal) (AI)	Derived from Beyer, Connor, and Gerould (1994); Collins and Boyajian (1965)
BLACK-NECKED STILT		
Mean body weight (BW) (kg)	0.2	Dunning (1993)
Minimum body weight (BW) (kg)	0.166	Dunning (1993)
Mean foraging area (ha)	24	Schoener (1968)
Mean food intake (mg/day, dry weight)	16,093 ^b	EPA (1993b)
Maximum food intake (mg/day, dry weight) (FI)	17,287 ^b	EPA (1993b)
Water intake (mL/day)	20.1 ^c	EPA (1993b)
Diet partition factor	0.15 (soil) (SI) 0.15 (plant) (PI) 0.85 (animal) (AI)	Derived from Bent (1962) (stilt sandpiper); Bent (1962) (black-necked stilt)

kg = kilogram

BW = body weight

ha = hectare

SI = soil ingestion

mg = milligram

PI = plant ingestion

mL = milliliter

AI = animal ingestion

^a Dry-weight food intake estimated based on algorithm given in EPA (1993b).

^b Water intake estimated based on algorithm given in EPA (1993b).

Body Weight (BW). The mean of the adult male and female body weight; minimum = lower 95 percent UCL of mean.

Food Intake (FI)/Day. The daily diet, in milligram of organic matter eaten per day, determined on a wet-weight basis.

Site Use Factor (SUF). The site use factor (i.e., foraging factor) is defined as follows:

$$SUF = \frac{\text{Area of Surface Soil Contamination}}{\text{Foraging Area of Animal}}$$

This factor permits consideration of less than full-time exposure for animals with foraging areas exceeding the area of contamination. When the foraging area of the receptor is less than the size of the site, it is assumed that the animal occupies the site 100 percent of the time, and the foraging factor is equal to 1. It is assumed that these receptors are continuously exposed to site contaminants.

Foraging area information for house mouse is based on the deer mouse (0.06 hectare) as provided by Wolff (1985). Because this is smaller than the site, it is assumed that the site use factor for the house mouse is 1. The foraging area for the northern cardinal is estimated at 0.15 hectare, based on data for the home range (Brewer 1955). The foraging area for the black-necked stilt is estimated at 24 hectares, based on the predator model of Schoener (1968) (see Appendix O.2).

Plants, earthworms, and aquatic invertebrates are assumed to spend their entire lives within the contaminated area; therefore, the SUF is not used in calculating exposure for the earthworm.

In Step 2 of this SERA, the SUF was conservatively set equal to 1 for all receptors.

Diet Partitioning Factor (DPF). Three major exposure pathways may define the diet of animal receptors:

- Direct ingestion of soil or sediment—soil/sediment ingestion (SI)
- Ingestion of contaminated plant materials—plant ingestion (PI)
- Ingestion of contaminated animal prey—animal ingestion (AI)

The proportion of diet from each source may be estimated or obtained from the literature. In Tier 1, the DPF was set to the diet proportions reported in the literature.

7.2.1.3 CHEMICAL-SPECIFIC EXPOSURE PARAMETERS

Chemical-specific characteristics, such as solubility, organic carbon partition coefficient, and bioconcentration and bioaccumulation factors, also affect exposure of representative species to COPECs.

Soil-to-Plant Bioconcentration Factor (BCF_p). BCF_p values are used to convert chemical concentrations in soil to concentrations in plant biomass resulting from plant root uptake. This factor is used to estimate the concentration of a COPEC that bioaccumulates in plants grown in contaminated soil during one growing season. This factor is also used to model concentrations of COPECs through plants to herbivores. Use of these factors assumes that plant root uptake for a specific chemical is equal for all plants.

The BCF_p value for the inorganic COPEC (lead) was obtained from Strenge and Peterson (1989). BCF_p values for organic COPECs were obtained from the literature or derived from a chemical-specific octanol-water partition coefficient (K_{ow}) by the method of Travis and Arms (1988). Some degree of uncertainty is associated with the use of this factor, especially for perennial plants. For the most part, however, animals feed on portions of the plants that are renewed annually (i.e., foliage, seeds, and fruit).

Soil-to-Earthworm Bioconcentration Factor (BCF_e). BCF_e values are used to convert chemical concentrations in soil to concentrations in invertebrate biomass resulting from both ingestion and integument sorption. This factor is used to estimate the concentration of a COPEC that bioaccumulates in earthworms living in contaminated soil. The factor is also used to model concentrations of COPECs through earthworms and other soil invertebrates to their predators.

Surface Water-to-Aquatic Invertebrate Bioconcentration Factor (BCF_i). BCF_i values are used to convert chemical concentrations in surface water to concentrations in invertebrate biomass resulting from both ingestion and integument sorption. This factor is used to estimate the concentration of a COPEC that bioaccumulates in aquatic invertebrates living in contaminated areas. The factor is also used to model concentrations of COPECs through invertebrates to their predators.

BCF_p, BCF_e, and BCF_i values for COPECs are listed in Table 7-10.

Table 7-10: Bioconcentration Factors for COPECs

Chemical	K _{ow} Source	BCF _p Source	BCF _e Source or Surrogate Chemical	BCF _i Source
Inorganics				
Lead	—	6.80E-02 Streng and Peterson (1989)	4.50E-01 Beyer and Stafford (1993)	1.00E+02 Streng and Peterson (1989)
Volatile Organics				
Acetone	5.80E-01 Streng and Peterson (1989)	5.31E+01 Streng and Peterson (1989)	1.0E+00 TCE as surrogate	4.57E-02 Calculated from K _{ow} (Travis and Arms 1988)
4-Bromophenyl- phenylether	Not available	1.25E-02 Aroclor 1254	Not used	Not used
2-Butanone	1.90E+00 Sample et al. (1998)	6.70E+00 Sample et al. (1998)	Not used	1.20E-01 Streng and Peterson (1989)
Carbon disulfide	1.00E+02 Streng and Peterson (1989)	6.80 E-01 Streng and Peterson (1989)	—	3.10E+00 Streng and Peterson (1989)
2-Nitrophenol	8.10E+01 Streng and Peterson (1989)	7.60E-01 Streng and Peterson (1989)	Not used	2.6E+00 Calculated from K _{ow} (Travis and Arms 1988)
Phenol	2.90E+01 Streng and Peterson (1989)	1.40E+00 Streng and Peterson (1989)	Not used	1.10E+00 Calculated from K _{ow} (Travis and Arms 1988)
PAH Group 1^a				
Anthracene	2.80E+04 Streng and Peterson (1989)	1.04E-01 Calculated from K _{ow} (Travis and Arms 1988)	3.20E-01 Beyer and Stafford (1993)	3.13E+02 Calculated from K _{ow} (Travis and Arms 1988)
Benzo(g,h,i)perylene	3.16E+06 ATSDR (1993)	6.78E-03 Calculated from K _{ow} (Travis and Arms 1988)	1.50E-01 Beyer and Stafford (1993)	1.50E+04 Calculated from K _{ow} (Travis and Arms 1988)
Fluoranthene	7.90E+04 Streng and Peterson (1989)	5.72E-02 Calculated from K _{ow} (Travis and Arms 1988)	3.70E-01 Beyer and Stafford (1993)	7.33E+02 Calculated from K _{ow} (Travis and Arms 1988)
Phenanthrene	2.90E+04 Streng and Peterson (1989)	1.02E-01 Calculated from K _{ow} (Travis and Arms 1988)	2.80E-01 Beyer and Stafford (1993)	3.23E+02 Calculated from K _{ow} (Travis and Arms 1988)

Chemical	K_{ow} Source	BCF_p Source	BCF_e Source or Surrogate Chemical	BCF_i Source
Pyrene	2.10E+05 Streng and Peterson (1989)	3.25E-02 Calculated from K_{ow} (Travis and Arms 1988)	3.90E-01 Beyer and Stafford (1993)	1.63E+03 Calculated from K_{ow} (Travis and Arms 1988)
PAH Group 2^a				
Benzo(a)anthracene	4.00E+05 Streng and Peterson (1989)	2.24E-02 Calculated from K_{ow} (Travis and Arms 1988)	2.70E-01 Beyer and Stafford (1993)	2.77E+03 Calculated from K_{ow} (Travis and Arms 1988)
Benzo(a)pyrene	1.20E+06 Streng and Peterson (1989)	1.19E-02 Calculated from K_{ow} (Travis and Arms 1988)	3.40E-01 Beyer and Stafford (1993)	6.80E+03 Calculated from K_{ow} (Travis and Arms 1988)
Benzo(b)fluoranthene	1.20E+06 Streng and Peterson (1989)	1.19E-02 Calculated from K_{ow} (Travis and Arms 1988)	2.10E-01 Beyer and Stafford (1993)	6.81E+03 Calculated from K_{ow} (Travis and Arms 1988)
Benzo(k)fluoranthene	1.20E+06 Streng and Peterson (1989)	1.19E-02 Calculated from K_{ow} (Travis and Arms 1988)	2.10E-01 Beyer and Stafford (1993)	6.81E+03 Calculated from K_{ow} (Travis and Arms 1988)
Chrysene	4.10E+05 Streng and Peterson (1989)	2.21E-02 Calculated from K_{ow} (Travis and Arms 1988)	4.40E-01 Beyer and Stafford (1993)	2.82E+03 Calculated from K_{ow} (Travis and Arms 1988)
Dibenzo(a,h) anthracene	4.10E+05 Streng and Peterson (1989)	5.70E-02 Calculated from K_{ow} (Travis and Arms 1988)	4.90E-01 Beyer and Stafford (1993)	2.82E+03 Calculated from K_{ow} (Travis and Arms 1988)
Indeno(1,2,3-cd) pyrene	3.20E+06 Streng and Peterson (1989)	6.73E-03 Calculated from K_{ow} (Travis and Arms 1988)	4.10E-01 Beyer and Stafford (1993)	1.52E+04 Calculated from K_{ow} (Travis and Arms 1988)
Phthalate Esters				
Bis(2-ethylhexyl) phthalate	4.10E+09 Streng and Peterson (1989)	1.08E-04 Calculated from K_{ow} (Travis and Arms 1988)	3.00E+01 EPA (1995)	5.33E+06 EPA (1995)
Diethylphthalate	2.90E+02 McDuffie, Russel, and Natishar (1984)	3.70E-01 Calculated from K_{ow} (Travis and Arms 1988)	7.40E+00 Streng and Peterson (1989)	7.40E+00 Streng and Peterson (1989)
Di-n-butylphthalate	4.00E+04 Maybey et al. (1982)	5.60E-03 Streng and Peterson (1989)	3.00E+01 EPA (1995)	3.00E+01 EPA (1995)

BCF_p = soil-to-plant bioconcentration factor

BCF_e = soil-to-earthworm bioconcentration factor

BCF_i = surface water-to-aquatic invertebrate bioconcentration factor

K_{ow} = octanol/water partition coefficient

— = not available

^a PAH grouping based on Massachusetts upper concentration limits allowed in soil and groundwater according to Method 3 Risk Characterization Standards (MCP 1995, Table 6). Group 1: 10,000 parts per million (ppm); Group 2: 100 or 400 ppm.

7.2.1.4 EXPOSURE EQUATIONS

Exposure factors were employed in equations to calculate uptake or intake for each exposure pathway. The equations used to derive intake values for animal receptors and uptake values for plant receptors are described below.

Surface soil concentrations of COPECs were used to estimate uptake values for plants and earthworms in mg/kg and intake values for the house mouse and northern cardinal in mg/kg-day. Sediment COPEC concentrations were used to estimate uptake values for aquatic plants and intake values for the black-necked stilt. Surface water COPEC concentrations were used to estimate uptake values for aquatic life, which is in turn eaten by the stilt.

In Step 2, the maximum COPEC concentrations were used in the equations as EPCs. A separate uptake or intake estimate was calculated for each species and each exposure pathway (see Appendix O.3). The total exposure for each species is the sum of exposure from all appropriate pathways presented in Section 7.1.2.

Soil/Sediment-to-Plant Exposure Pathway. Plant contaminant concentrations for koa haole were estimated from site soil COPEC concentrations in the 0–6-inch soil interval using the BCF_p . Plant contaminant concentrations for watercress were estimated from site sediment COPEC concentrations in the 0–6-inch sediment interval using the BCF_p . Equation 7-1 describes this pathway.

Equation 7-1: Model for Estimating Plant Uptake of COPECs from Soil or Sediment

$$C_p = C_s \times BCF_p$$

Where:

- C_p = COPEC concentration in plant (mg/kg)
- C_s = COPEC concentration in surface soil or sediment (mg/kg)
- BCF_p = soil-to-plant bioconcentration factor (unitless)

Assumptions:

- Concentrations of COPECs in surface soil or sediment (C_s) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in the Tier 2 assessment. These values are presented in Table 7-7.
- BCF_p is a chemical-specific factor relating soil concentration to plant tissue equilibrium concentration on a dry-weight basis.

Soil-to-Invertebrate-to-Predator Exposure Pathway. This pathway is analogous to the soil-to-plant-to-herbivore pathway in that it represents a feeding relationship. In both cases, the animal ingests tissue with a contaminant concentration expressed in milligram of chemical per kilogram of tissue (dry weight). Invertebrate tissue burden for each contaminant was estimated using BCF_e because exposure of soil invertebrates such as the earthworm via ingestion and sorption through the integument cannot be separated. Equation 7-2 describes this pathway.

Equation 7-2: Model for Estimating Soil Invertebrate Uptake of COPECs from Soil

$$C_e = C_s \times BCF_e$$

Where:

- C_e = COPEC concentration in earthworm (mg/kg)
- C_s = COPEC concentration in surface soil (mg/kg)
- BCF_e = soil-to-earthworm bioconcentration factor (unitless)

Assumptions:

- Concentrations of COPECs in surface soil (C_s) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- BCF_e is a chemical-specific factor relating soil concentration to earthworm-tissue-equilibrium concentration on a dry-weight basis.

Soil/Sediment Ingestion Exposure Pathway. A major cause of exposure to soil contaminants for many animals, including the house mouse and northern cardinal, is assumed to be direct soil ingestion. This occurs as a result of preening by birds, grooming of the pelt by mammals, deliberate soil ingestion (e.g., to aid in digestion and as a source of nutrients), and accidental soil ingestion

while feeding (Kreulen and Jager 1984). The black-necked stilt is assumed to ingest sediment when feeding. Equation 7-3 presents the model used to estimate exposure by soil or sediment ingestion.

Equation 7-3: Model for Estimating Animal Intake of COPECs from Ingestion of Soil or Sediment

$$CDI \text{ (mg/kgday)} = \frac{CS \times FI \times SI \times CF \times SUF}{BW}$$

Where:

CDI	=	chronic daily intake (mg/kg-day)
C _s	=	COPEC concentration in surface soil or sediment (mg/kg)
FI	=	total food intake (mg/day)
SI	=	soil ingestion expressed as fraction of total food intake (unitless)
CF	=	conversion factor (10 ⁻⁶ kg/mg)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Assumptions:

- Concentrations of COPECs in surface soil or sediment (C_s) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- SI, FI, and BW are values obtained from peer-reviewed literature and are presented in Table 7-9.
- SUF is calculated as the ratio of the area of suitable habitat available at each site to the animal foraging area. Thus, the SUF is both species- and site-specific. The maximum value for SUF is 1. The foraging area used for each pathway calculation is presented in Table 7-9.

Soil/Sediment-to-Plant-to-Animal Exposure Pathway. The model used to estimate the contaminant intake concentration resulting from this pathway is presented in Equation 7-4. This model pertains both to ingestion of vegetation and seeds by the house mouse and the northern cardinal. It also applies to the ingestion of aquatic plants such as watercress or algae, by the black-necked stilt.

Equation 7-4: Model for Estimating Animal Intake of COPECs from Ingestion of Plants

$$CDI \text{ (mg/kg - day)} = \frac{C_s \times BCF_p \times CF \times FI \times PI \times SUF}{BW}$$

Where:

CDI	=	chronic daily intake (mg/kg-day)
C _s	=	COPEC concentration in surface soil or sediment (mg/kg)
BCF _p	=	soil-to-plant bioconcentration factor (unitless)
CF	=	conversion factor (10 ⁻⁶ kg/mg)
FI	=	total food intake (mg/day)
PI	=	plant ingestion expressed as fraction of total food intake (unitless)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Assumptions:

- Concentrations of COPECs in surface soil or sediment (C_s) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- SUF is calculated as the ratio of the area of suitable habitat available at each site to the animal foraging area. Thus, the SUF is both species- and site-specific. The foraging area used for each pathway calculation is presented in Table 7-9.

Soil-to-Invertebrate-to-Predator Exposure Pathway. This pathway is analogous to the soil-to-plant-to-herbivore pathway in that it represents a feeding relationship. In both cases, the animal ingests tissue with a contaminant concentration expressed in milligram of chemical per kilogram of tissue (dry weight). The northern cardinal ingests earthworms from soil and the black-necked stilt ingests aquatic invertebrates found in the aquatic environment. Equation 7-5 presents the model used to estimate exposure via this pathway.

Equation 7-5: Model for Estimating Animal Intake of COPECs from Ingestion of Soil Invertebrates

$$CDI (mg/kg \cdot day) = \frac{C_s \times BCF_e \times CF \times FI \times AI \times SUF}{BW}$$

Where:

CDI	=	chronic daily intake (mg/kg-day)
C _s	=	COPEC concentration in surface soil (mg/kg)
BCF _e	=	soil-to-earthworm bioconcentration factor (unitless)
CF	=	conversion factor (10 ⁻⁶ kg/mg)
FI	=	total food intake (mg/day)
AI	=	animal ingestion expressed as fraction of total food intake (unitless)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Assumptions:

- Concentrations of COPECs in surface soil (C_s) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- SUF is calculated as the ratio of the area of suitable habitat available at each site to the animal foraging area. Thus, the SUF is both species- and site-specific. The foraging area used for each pathway calculation is presented in Table 7-9.

Surface Water-to-Aquatic Bird Pathway. This pathway is used to estimate the intake of chemicals in surface water via direct ingestion by aquatic birds such as the black-necked stilt. The exposure model used for this pathway is given in Equation 7-6.

Equation 7-6: Model for Estimating Animal Intake of COPECs from Ingestion of Surface Water

$$CDI = \frac{C_{sw} \times WI \times SUF}{BW}$$

Where:

CDI	=	chronic daily intake (mg/kg-day)
C _{sw}	=	COPEC concentration in surface water (mg/L)
WI	=	water intake (L/day)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Assumptions:

- Concentrations of COPECs in surface water (C_{sw}) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- SUF is calculated as the ratio of the area of suitable habitat available at each site to the animal foraging area. Thus, the SUF is both species- and site-specific. The foraging area and habitat area used for each pathway calculation are presented in Table 7-9.

Surface Water-to-Aquatic Life-to-Predator Exposure Pathway. This pathway is analogous to the soil-to-plant-to-herbivore pathway in that it represents a feeding relationship. In both cases, the animal ingests tissue with a contaminant concentration expressed in milligram of chemical per kilogram of tissue (dry weight). The black-necked stilt ingests aquatic organisms found in the aquatic environment. Equation 7-7 presents the model used to estimate exposure via this pathway.

Equation 7-7: Model for Estimating Animal Intake of COPECs from Ingestion of Aquatic Organisms

$$CDI = \frac{C_{sw} \times BCF_i \times CF \times FI \times AI \times SUF}{BW}$$

Where:

CDI	=	chronic daily intake (mg/kg-day)
C_{sw}	=	COPEC concentration in surface water (mg/L)
BCF_i	=	water-to-invertebrate (aquatic life), bioconcentration factor (unitless)
CF	=	conversion factor (10^{-6} kg/mg)
FI	=	total food intake (mg/day)
AI	=	aquatic organism ingestion expressed as a fraction of total food intake (unitless)
SUF	=	site use factor (unitless)
BW	=	body weight (kg)

Assumptions:

- Concentrations of COPECs in surface water (C_{sw}) are represented by the maximum in Tier 1 assessments and by the 95% UCL or the maximum, whichever is less, in Tier 2 assessments. These values are presented in Table 7-7.
- SUF is calculated as the ratio of the area of suitable habitat available at each site to the animal foraging area. Thus, the FF is both species- and site-specific. The foraging area and habitat area used for each pathway calculation are presented in Table 7-9.

Total exposure for each species at the site is equal to the sum of exposure from all appropriate pathways.

7.2.2 Calculation of Ecological Soil Screening Levels

Ecological soil screening levels (Eco-SSLs) are COPEC concentrations in soil that are considered conservative, screening-level concentrations. If the Eco-SSL for a COPEC at a site is not exceeded by COPEC EPCs, further evaluation is not required. Conversely, if the Eco-SSL is exceeded, further evaluation may be required.

Eco-SSL calculations are based on the HQ methodology (see Section 7.2.3.1):

$$HQ = \text{Intake} / TRV$$

Eco-SSLs are calculated by setting the HQ equal to one and “back-calculating” soil concentrations using the above exposure equations (representing “intake”) for all pathways applicable to a particular receptor.

The equation used to determine Eco-SSLs is based on a combination of the following models that were applied to exposure pathways for house mouse, northern cardinal, and black-necked stilt:

- Estimating animal intake of COPECs by soil/sediment ingestion (see Equation 7-3)
- Estimating animal intake of COPECs by ingestion of plants (see Equation 7-4)
- Estimating animal intake of COPECs by ingestion of soil/ invertebrates (Equation 7-5)

$$HQ = \frac{\text{intake}_{(\text{soil/sediment ingestion})}}{TRV} + \frac{\text{intake}_{(\text{plant ingestion})}}{TRV} + \frac{\text{intake}_{(\text{soil invertebrate ingestion})}}{TRV}$$

$$HQ = \frac{\left(\frac{C_s \times FI \times SI \times CF \times FF}{BW} \right)}{TRV} + \frac{\left(\frac{C_s \times BCF_p \times CF \times FI \times PI \times FF}{BW} \right)}{TRV} + \frac{\left(\frac{C_s \times BCF_e \times CF \times FI \times AI \times FF}{BW} \right)}{TRV}$$

Assuming HQ = 1, then

$$C_s = \frac{BW \times TRV}{(FI \times SI \times CF \times FF) + (BCF_p \times CF \times FI \times PI \times FF) + (BCF_e \times CF \times FI \times AI \times FF)}$$

The Eco-SSL selected for comparison against site soil EPCs was the lower (more conservative) of the house mouse or northern cardinal Eco-SSL. The black-necked stilt Eco-SSL was used for comparison against sediment EPCs.

The Eco-SSLs used for screening are presented in Table 7-11. These values were compared to soil and sediment EPCs to estimate potential for risk of adverse effects in the following section.

Table 7-11: Site-Specific Eco-SSLs for Representative Species

COPEC	House Mouse (mg/kg) ^a	Northern Cardinal (mg/kg)	Black-Necked Stilt (mg/kg) ^a
Inorganic			
Lead	7.0E-02	2.6E-01	2.3E-01
PAH Group 1			
Anthracene	2.22E+03	4.39E+02	4.35E+02
Benzo(g,h,i)perylene	6.32E+03	1.10E+03	7.65E+02
Fluoranthene	2.54E+03	4.85E+02	4.27E+02
Phenanthrene	2.70E+03	5.38E+02	5.50E+02
Pyrene	2.78E+03	5.19E+02	4.28E+02
PAH Group 2			
Benzo(a)anthracene	4.73E+01	6.95E+01	5.46E+01
Benzo(a)pyrene	4.33E+01	6.30E+01	4.82E+01
Benzo(b)fluoranthene	6.06E+01	8.69E+01	6.41E+01
Benzo(k)fluoranthene	6.06E+01	8.69E+01	6.41E+01
Chrysene	3.75E+01	5.42E+01	4.11E+01
Dibenz(a,h)anthracene	3.10E+01	4.60E+02	3.71E+02
Indeno(1,2,3-cd)pyrene	3.87E+01	5.62E+01	4.29E+01
Misc. Organic			
Acetone	2.12E+01	1.71E+01	4.21E+01
2-Butanone	1.44E+03	6.44E+01	9.71E+01
4-Bromophenyl-phenylether	NC	NC	NC

COPEC	House Mouse (mg/kg) ^a	Northern Cardinal (mg/kg)	Black-Necked Stilt (mg/kg) ^b
Carbon disulfide	1.97E+03	8.74E+01	1.60E+02
Phenol	5.56E+03	2.60E+02	5.48E+02
Phthalate esters			
BEHP	2.27E+01	4.80E-01	4.10E-01
Diethylphthalate	8.04E+03	2.56E+02	2.33E+02
Di-n-butylphthalate	2.75E+02	5.00E-02	4.00E-02

NC = not a COPEC in this medium

^a Soil Eco-SSL, lowest of mammal or bird value

^b Sediment Eco-SSL based on stilt exposure assumptions.

7.2.3 Risk Calculations

Descriptions and results of risk calculations are presented here. Descriptions include the HQ method used to estimate risk for each aquatic and terrestrial pathway for each representative species. This is accomplished by dividing each EPC in each medium by appropriate media screening concentrations.

7.2.3.1 HAZARD QUOTIENTS

Toxicity and exposure information are integrated to predict possible adverse effects to ecological receptors (i.e., the potential environmental effect of a given COPEC). The HQ method is used to screen sites when potential adverse effects to ecological receptors occur. It provides an evaluation of the potential environmental effect of a given COPEC. The method compares estimates of uptake (for plants) or intake (for animals) to the respective TRV; this comparison is expressed as a HQ—the quotient of the ratio of uptake or intake to the TRV. If the HQ value is greater than 1, a receptor has a potential for adverse effects due to exposure to a contaminant via a specific exposure pathway.

Ecological HQ Equations. HQ values were determined for each COPEC and exposure pathway affecting the selected receptors at each site. The HQ values were calculated using the following equations.

- Plant Equation:

$$HQ = \frac{\text{Uptake of COPEC by Plant}}{\text{TRV for COPEC for Plant}}$$

- Aquatic Organism Equation:

$$HQ = \frac{\text{COPEC Concentration in Surface Water or Sediment}}{\text{Surface Water or Sediment Screening Value}}$$

- Terrestrial and Semi-aquatic Animal Equation:

$$HQ = \frac{\text{Intake of COPEC by Animal Receptor}}{\text{TRV for COPEC for Animal Receptor}}$$

Where: HQ = The hazard quotient calculated for a given exposure pathway

These chemical-specific HQs were added together to determine an HQ pathway sum (HQ_{sum}) that expresses risk to each receptor resulting from exposure to a contaminant for all exposure pathways at the site:

$$HQ_{sum} = \sum_i^n HQ_i$$

Where: HQ_{sum} = Sum of all HQ values for chemical X , receptor Y , site Z , for pathways i through the n th pathway
 n = Number of pathways assessed for chemical X , receptor Y , site Z

A HQ value exceeding 1 indicates that the exposure level exceeds the effects level for the receptor being assessed; therefore, due to exposure to a COPEC via a variety of pathways, the potential for adverse effects exists. HQ values exceeding 1 do not necessarily indicate that an effect will occur, only that a lower threshold has been exceeded based on the exposure assumptions used in the model. It should be noted that a single chemical or pathway might be the driving force for an HQ for a plant or animal at a site.

Note that the HQ as an evaluation of a measurement endpoint provides some insight into general effects on individual plant and animal reproduction or survival in the local population. It is assumed that if effects are judged insignificant for the average individual receptor, they will be considered insignificant at the population level. However, if risks are present at the individual receptor level, risks may or may not be important at the population level because density dependent population control mechanisms may compensate for the loss of several individuals. Since endangered species are valued as individuals, risks to individuals are considered unacceptable.

HQ values calculated for COPECs are presented in Appendix O.3 for each exposure pathway for each representative species using conservative Step 2 exposure assumptions.

7.2.3.2 COMPARISON OF EPCs TO SCREENING CONCENTRATIONS

COPEC concentrations in the various media were compared to appropriate screening concentrations.

7.2.3.3 COMPARISONS OF EPCs TO SURFACE WATER SCREENING CONCENTRATIONS

Surface water analytical results in the wetlands and hydric crop fields were screened against federal NRWQC and Hawaii chronic WQSs for the protection of aquatic life. If neither state nor federal criteria were available, Great Lakes Tier 2 values presented in Suter and Tsao (1996) were used as tertiary screening values. The comparison is presented in Table 7-12.

No Hawaii WQS and few NRWQC have been established for the organic COPECs detected in the offsite wetland/agricultural area. Great Lakes Tier 2 screening criteria have been developed for several organic COPECs (Suter and Tsao 1996) and they have been included as screening criteria. For those chemicals detected in surface waters that lack screening criteria, potential risks to aquatic life are underestimated and uncertain.

Table 7-12: Comparison of Surface Water COPECs to Chronic Surface Water Screening Values for the Protection of Aquatic Life, EJFDF Phase II RI

COPEC	Marine						Freshwater									
	Hawaii Chronic WQS	NRWQC	Great Lakes Tier 2	Offsite Sampling Location			Hawaii Chronic WQS	NRWQC	Great Lakes Tier 2	Offsite Sampling Location						
				W-01	W-02	W-04				W-06	W-09	W-03	W-05	W-07	W-08	W-10
SVOCs (µg/L) by CLP OLM 03.1																
Benzo(a)anthracene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	11J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(a)pyrene	NS	NS	0.014	0.02U	0.02U	0.02U	0.02U	11J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(b)fluoranthene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(g,h,i)perylene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	11J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
Benzo(k)fluoranthene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
BEHP	NS	360	32	8.7J	0.83J	10U	10U	10U	10U	NS	360	0.405J	10U	NW	NW	10U
Butylbenzylphthalate	NS	3.4 C	19.0	10U	10U	2.4J	10U	10U	10U	NS	3.0 C	0.501J	10U	NW	NW	10U
Chrysene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	15J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
Di-n-octylphthalate	NS	3.4 C	NS	0.643J	10U	0.865J	10U	10U	10U	NS	3.0 C	10U	10U	NW	NW	0.02U
Dibenzo(a,h)anthracene	NS	NS	NS	10U	10U	10U	0.337J	10U	10U	NS	NS	10U	10U	NW	NW	10U
Fluoranthene	NS	16	NS	0.02U	0.02U	0.02U	0.02U	33J	0.02U	NS	16 sw	18J	0.02U	NW	NW	16J
Indeno(1,2,3-cd)pyrene	NS	NS	NS	0.02U	0.02U	0.02U	0.02U	12J	0.02U	NS	NS	0.02U	0.02U	NW	NW	0.02U
2-Nitrophenol	NS	NS	NS	10U	10U	10U	10U	10U	10U	NS	150 C	2.35J	10U	NW	NW	10U
Phenanthrene	NS	4.6	NS	0.02U	0.02U	0.02U	0.02U	16J	0.02U	NS	6.3	11J	0.02U	NW	NW	0.02U
Pyrene	NS	NS	NS	10U	0.02U	0.02U	0.02U	27J	0.02U	NS	NS	17J	0.02U	NW	NW	16J
Lead (µg/L) by EPA 6010A																
Lead	5.6	8.1	NS	8.38J	1U	2.18J	79.71J	ND	29	2.5	NS	22.73J	97.58J	NW	NW	22.91J

Note: Surface water samples with VOC and SVOC concentrations below the MRLs are not included in this table.

Data qualifiers are defined in Section 4.5.

C = Screening value developed for a chemical class.

sw = If no freshwater criteria are available, saltwater criteria used as a surrogate.

NW = No water present at site at time of sampling

NS = No state or federal standard

Bold italic number = detected concentration above the MRL but below the screening criteria.

Boxed number = detected concentration above the screening criteria. HQ exceeds 1.

Saltwater Areas. Sample W-01 was collected at the outfall of a storm sewer draining parts of the Leeward Community College property. The lead concentration in surface water at W-01 slightly exceeds the screening value of 5.6 µg/L, but the HQ rounds to 1, indicating acceptable risk to aquatic organisms. Sample W-06 was collected in the drainage ditch from the Sasaki watercress fields. The water contained at least 3 PAHs (benzo(a)pyrene, fluoranthene and phenanthrene) at concentrations exceeding the screening level (other PAHs detected had no screening values).

Freshwater Areas. Within the watercress fields, lead was found at concentrations exceeding NRWQC at all three sampling locations. Fluoranthene and phenanthrene concentrations in surface water at sample location W-03 slightly exceed the aquatic life screening values, but the HQ rounds to 1.

Examination of the COPEC list reveals that the majority of the detected chemicals have low solubility and a high tendency to bind to sediment particles. Large volumes of water flow from the artesian wells that supply the watercress ponds. The artesian well water does not contain detectable levels of the COPECs detected in the surface water samples. Because the surface water samples were collected downstream of the artesian wells and were not filtered, it is probable that the detected COPECs are primarily bound to suspended or colloidal particles, and are therefore unavailable for uptake by aquatic organisms.

7.2.3.4 COMPARISONS OF EPCS TO SEDIMENT SCREENING CONCENTRATIONS

COPEC concentrations in sediment samples collected from the offsite area were compared to sediment screening values in Table 7-13.

Saltwater Areas. Samples D-01 and D-02 were collected at outfalls in the mangrove community located on the harbor side of the bicycle path. No COPECs were detected in these samples at concentrations above their respective saltwater ER-L screening values (Long et al. 1995); however, detection limits for dibenzo(a,h)anthracene were above the ER-L screening value.

Samples D-04, D-06, and D-09 were collected in the tidal ditches located below the watercress fields. The ditches collect excess irrigation water and discharge it to Pearl Harbor. The ditches are subject to tidal flushing and are considered brackish water. As such, COPECs in these three samples were compared to saltwater ER-L screening values. Lead detected at D-06 and D-03 slightly exceeds the screening value, but the HQs round to 1. No estuarine sediment samples contained PAHs at levels exceeding screening criteria. However, criteria are lacking for several PAHs detected in estuarine sediments. Therefore, the concentrations of all light-molecular-weight (LMW) PAHs were totaled, and concentrations of heavy-molecular-weight (HMW) PAHs were also totaled. The total concentrations were compared to their respective freshwater screening criteria (saltwater criteria are lacking). Neither total LMW nor HMW PAHs exceed the criteria at any of the sample locations. Therefore, risk to benthic organisms from PAHs in the offsite estuarine sediments is considered acceptable.

Table 7-13: Comparison of Sediment COPECs to Sediment Screening Values for the Protection of Benthic Organisms, EJFDF Phase II RI

COPEC	ER-L	Marine						Freshwater					
		Offsite Sampling Location						Offsite Sampling Location					
		D-01	D-02	D-04	D-06	D-09	TEL	D-03	D-05	D-07	D-08	D-10	D-10 Duplicate
Volatiles (µg/kg) by CLP OLM 03.1													
Acetone	ns	16.59J	16.81U	28.82U	74.84J	57.81J	ns	23.26UJ	21.58J	23.65J	15.43U	60.72J	67.66J
2-Butanone	ns	6.89J	16.81U	28.82U	26.89J	24.46J	ns	18.78J	15.29UJ	16.34U	15.43U	25.62J	37.45UJ
Carbon disulfide	ns	13.53U	16.81U	28.82U	37.74UJ	21.55UJ	ns	23.26UJ	15.29UJ	16.34U	15.43U	28.65UJ	8.36J
SVOCs (µg/kg) by CLP OLM 03.1													
Anthracene (LMW)	85.3	5U	5U	5UJ	5UJ	5U	ns	5UJ	12J	5U	5U	5U	5UJ
Benzo(a)anthracene (HMW)	261	14J	5U	6J	11J	23.69J	31.7	22J	42J	5U	5U	13J	5UJ
Benzo(a)pyrene (HMW)	430	9J	5U	12J	5UJ	19.56J	31.9	24J	50J	5U	5U	5U	5UJ
Benzo(b)fluoranthene (HMW)	ns	13J	5U	47.94J	15.3J	41.76J	ns	28J	82J	5U	5U	14J	12J
Benzo(g,h,i)perylene (LMW)	ns	21J	5U	115.7J	11J	5U	ns	22J	70J	5U	5U	11J	7J
Benzo(k)fluoranthene (HMW)	ns	7J	5U	11J	12J	5U	ns	27.18J	66J	5U	5U	13J	9J
BEHP	ns	1,798J	554.6U	73.63J	66.8J	34.06J	ns	42.47J	25.57J	26.61J	30.7J	945.6UJ	1,236UJ
4-Bromophenyl-phenylether	ns	446.5U	554.6U	951UJ	330UJ	197.1J	ns	767.4UJ	504.6UJ	330U	330U	945.6UJ	1,236UJ
Chrysene (HMW)	384	30J	5U	27.33J	16J	22.31J	57	41J	70J	5U	5U	14J	8J
Dibenzo(a,h)anthracene (HMW)	63.4	446.5U	554.6U	951UJ	330UJ	711.2U	ns	767.4UJ	20.97J	330U	330U	945.6UJ	1,236UJ
Diethylphthalate	ns	446.5U	554.6U	41.3J	330UJ	711.2U	ns	767.4UJ	504.6UJ	330U	330U	945.6UJ	1,236UJ
Fluoranthene (HMW)	600	20J	5J	24J	22J	5U	111	58J	84J	6J	5U	25J	19J
Hexachlorobutadiene	ns	446.5U	554.6U	951UJ	330UJ	711.2U	ns	767.4UJ	504.6UJ	330U	330U	945.6UJ	1,236UJ
Indeno(1,2,3-cd)pyrene (HMW)	ns	9J	5U	28.93J	16J	5U	ns	27J	79J	5U	5U	13J	8J
Phenanthrene (LMW)	240	26J	5U	14J	8J	5U	41.9	21J	18J	5U	5U	8J	7J
Phenol	ns	44.65UJ	554.6U	951UJ	330UJ	38.06J	ns	61.2J	504.6UJ	330U	330U	945.6UJ	1,236UJ
Pyrene (HMW)	665	67J	5U	40.86J	20J	5U	53	47J	66J	5U	5U	20J	18J
Total LMW PAHs	552	49.5	7.5	132.2	21.5	7.5	552sw	45.5	100	7.5	7.5	21.5	16.5
Total HMW PAHs	1700	418	297.3	673.56	279.8	472.92	1700sw	657.88	560	188.5	185	587.3	697
Lead (mg/kg) by EPA 6010A													
Lead	46.7	22.9824J	9.637J	26.0346J	56.1434J	7.6293J	35	42.3907J	8.6667J	4.5229J	5.2438J	25.2493J	12.3221J

Notes: All sampling depths = 0-0.5 feet.

Samples D-01, D-02, D-04, D-06 and D-09 were collected along the shoreline of the harbor and in tidal ditches, so they were screened against marine sediment values.

Samples D-03, D-05, D-07, D-08, and D-10 were collected inland of the harbor and were screened against freshwater sediment values.

Sediment samples with VOC, SVOC, and lead concentrations below the MRLs are not included.
 Data qualifiers are defined in Section 4.5.
 ns = No screening criterion available
 sw = If no freshwater criteria are available, salt-water criteria used as a surrogate.
 LMW = Low molecular weight
 HMW = High molecular weight
Boxed *Italic* number = detected concentration above the MRL but below the screening criteria.
 number = detected concentration above the screening criteria (HQ exceeds 1).

Freshwater Areas. The remaining samples were collected from freshwater sites in the watercress farm area. COPEC concentrations in these samples were compared to freshwater TELs (Smith et al. 1996). Concentrations of four of the PAHs (benzo(a)anthracene, benzo(a)pyrene, chrysene, and pyrene) detected in sample D-05 slightly exceed the screening values but the HQs round to 1. In addition, criteria are lacking for several PAHs detected in sediments. Therefore the concentrations of all LMW PAHs were totaled, and concentrations of HMW PAHs were also totaled. The total concentrations were compared to their respective freshwater screening criteria. Neither total LMW nor HMW PAHs exceed the criteria at any of the sample locations. Therefore, risk to benthic organisms from PAHs in the offsite freshwater sediments is considered acceptable.

Lead concentrations detected in sample D-03 slightly exceed the screening value, but the HQ rounds to 1. Risk to benthic organisms from lead in the offsite sediments is also considered acceptable.

7.2.3.5 COMPARISONS OF EPCS TO SOIL SCREENING CONCENTRATIONS

Soil and sediment screening concentrations presented in this section were calculated using the conservative exposure and toxicity assumptions for Step 2 of this SERA. The soil screening concentrations are referred to as Step 2 Eco-SSLs. The EPCs that were compared to these values represent maximum COPEC concentrations.

Table 7-14 lists maximum concentrations and Eco-SSLs for each soil COPEC. Also presented is a species-specific Eco-SSL for each receptor. The HQ value for each receptor is calculated by dividing the maximum COPEC concentration by the COPEC-specific SSL. The Step 2 Eco-SSLs and HQ values for the black-necked stilt are given for the sediment COPECs in Table 7-15.

Maximum lead concentrations in soils exceed the lead soil screening levels based on exposure assumptions that are protective of small omnivorous birds and mammals. Maximum lead concentrations in sediments exceed the sediment screening value based on exposure assumptions protective of the black-necked stilt. In addition, BEPH exceeds the sediment screening value developed to protect the stilt (HQ = 4).

7.2.4 Uncertainty Analysis

Ecological risk assessment results depend primarily on the weight of evidence supporting particular conclusions, and each line of evidence is subject to varying degrees of uncertainty. Due to the complexity of ecosystems and the associated mechanisms that cause ecological stress, uncertainty in environmental risk characterization is inevitable. Uncertainty stems from a number of sources, including but not limited to the following:

- Sampling and statistical variability
- Limitations of toxicity testing
- Difficulty of extrapolating from laboratory data to field data
- Problems in evaluating environmental responses to mixtures of contaminants
- Assumptions underlying the use of fate and transport models
- Range of conditions for which models or hazard indexes are applicable

Other uncertainty sources include unexpected weather conditions or sources of contamination.

Table 7-14: Comparison of Maximum Concentrations of Chemicals Detected in Site Surface Soils to Eco-SSLs Based on House Mouse or Northern Cardinal Exposure, EJFDF Phase II RI

Chemical Name	EPA/U.S. Navy BTAG-Low TRV (mg/kg-day)			Eco-SSL (mg/kg)		Maximum Concentration in Surface Soil (mg/kg)		HQ	
	Mammal	Bird		House Mouse	Northern Cardinal			House Mouse	Northern Cardinal
Inorganic									
Lead	3.92E-03	1.40E-02		7.00E-02	2.60E-01	4.43E+01		6.32E+02	1.70E+02
PAH Group 1									
Anthracene	1.21E+02	2.30E+01		2.22E+03	4.39E+02	3.00E-03		1.35E-06	6.83E-06
Benzo(g,h,i)perylene	1.21E+02	2.30E+01		6.32E+03	1.10E+03	3.30E-02		5.22E-06	3.00E-05
Fluoranthene	1.21E+02	2.3E+01		2.54E+03	4.85E+02	3.20E-02		1.25E-05	6.59E-05
Phenanthrene	1.21E+02	2.3E+01		2.70E+03	5.38E+02	1.40E-02		5.18E-06	2.60E-05
Pyrene	1.21E+02	2.3E+01		2.78E+03	5.19E+02	3.20E-02		1.15E-05	6.16E-05
PAH Group 2									
Benzo(a)anthracene	1.51E+00	2.25E+00		4.73E+01	6.95E+01	2.10E-02		4.43E-04	3.02E-04
Benzo(a)pyrene	1.51E+00	2.25E+00		4.33E+01	6.30E+01	1.70E-02		3.92E-04	2.69E-04
Benzo(b)fluoranthene	1.51E+00	2.25E+00		6.06E+01	8.69E+01	3.40E-02		5.61E-04	3.91E-04
Benzo(k)fluoranthene	1.51E+00	2.25E+00		6.06E+01	8.69E+01	2.00E-02		3.30E-04	2.30E-04
Chrysene	1.51E+00	2.25E+00		3.75E+01	5.42E+01	2.70E-02		7.20E-04	4.98E-04
Dibenz(a,h)anthracene	1.51E+00	2.25E+00		3.10E+01	4.60E+02	1.60E-02		5.16E-04	3.47E-05
Indeno(1,2,3-cd)pyrene	1.51E+00	2.25E+00		3.87E+01	5.62E+01	1.80E-02		4.65E-04	3.20E-04
Misc. Organic									
Acetone	2.61E+02	1.70E+02		2.12E+01	1.71E+01	NC		—	—
4-Bromophenyl-phenylether	NC	—		—	NC	NC		—	—
2-Butanone	4.52E+02	1.73E+01		1.44E+03	6.44E+01	NC		—	—
Carbon disulfide	3.29E+02	1.26E+01		1.90E+03	8.74E+01	NC		—	—
2-Nitrophenol	NC	1.40E+01		—	NC	NC		—	—
Phenol	1.88E+03	7.21E+01		5.56E+03	2.60E+02	NC		—	—
Phthalate Esters									
BEHP	5.22E+01	1.10E+00		2.27E+01	4.80E-01	6.00E-02		2.64E-03	1.25E-01
Diethylphthalate	5.28E+03	1.63E+02		8.03E+03	2.56E+02	NC		—	—
Di-n-butylphthalate	6.34E+02	1.10E-01		2.75E+02	5.00E-01	—		—	—

mg/kg-day = milligram of chemical per kilogram of body weight per day

BTAG = Biological Technical Assistance Group (PRC 1998)

Boxed number = Soil concentration exceeds the respective Eco-SSL; HQ exceeds 1.

NC = not a COPEC in this medium

— = not available

Table 7-15: Comparison of Maximum Concentrations of Chemicals Detected in Site Sediment to Eco-SSLs Based on Black-Necked Stilt Exposure, EJFDF Phase II RI

Chemical Name	EPA/US Navy BTAG-Low (mg/kg-day): Bird	Eco-SSL (mg/kg): Black-Necked Stilt	Maximum Concentration		HQ	
			Marine Sediment (mg/kg)	Freshwater Sediment (mg/kg)	Marine Sediment	Freshwater Sediment
Inorganic						
Lead	1.40E-02	2.30E-01	5.61E+01	4.23E+01	2.43E+02	1.83E+02
PAH Group 1						
Anthracene	1.21E+02	4.35E+02	NC	1.20E-02	—	2.75E-05
Benzo(g,h,i)perylene	1.21E+02	7.65E+02	1.16E-01	7.00E-02	1.51E-04	9.15E-05
Fluoranthene	1.21E+02	4.27E+02	2.20E-02	8.40E-02	5.15E-05	1.96E-04
Phenanthrene	1.21E+02	5.50E+02	2.60E-02	2.10E-02	4.72E-05	3.81E-05
Pyrene	1.21E+02	4.28E+02	6.70E-02	6.60E-02	1.56E-04	1.54E-04
PAH Group 2						
Benzo(a)anthracene	1.51E+00	5.46E+01	2.36E-02	4.20E-02	4.32E-04	7.69E-04
Benzo(a)pyrene	1.51E+00	4.82E+01	1.95E-02	5.00E-02	4.04E-04	1.03E-03
Benzo(b)fluoranthene	1.51E+00	6.41E+01	4.79E-02	8.20E-02	7.47E-04	1.27E-03
Benzo(k)fluoranthene	1.51E+00	6.41E+01	1.20E-02	6.60E-02	1.87E-04	1.02E-03
Chrysene	1.51E+00	4.11E+01	2.73E-02	7.00E-02	6.64E-04	1.70E-03
Dibenzo(a,h)anthracene	1.51E+00	3.71E+02	NC	2.09E-02	—	5.63E-05
Indeno(1,2,3-cd)pyrene	1.51E+00	4.29E+01	2.89E-02	7.90E-02	6.73E-04	1.84E-03
Misc. Organic						
Acetone	2.61E+02	4.21E+01	7.48E-02	6.07E-02	1.77E-03	1.44E-03
4-Bromophenyl-phenylether	NC	—	1.97E-01	NC	—	—
2-Butanone	4.52E+02	9.71E+01	2.68E-02	2.56E-02	2.76E-04	2.60E-04
Carbon disulfide	3.29E+02	1.60E+02	NC	8.36E-03	—	5.22E-05
2-Nitrophenol	NC	NC	NC	NC	—	—
Phenol	1.88E+03	5.48E+02	3.80E-02	6.10E-02	6.93E-05	1.11E-04
Phthalate Esters						
BEHP	5.22E+01	4.10E-01	1.79E+00	4.24E-02	4.36E+00	1.03E-01
Diethylphthalate	5.28E+03	2.33E+02	4.13E-02	NC	1.77E-04	—
Di-n-butylphthalate	6.34E+02	4.00E-02	NC	NC	—	—
mg/kg-day = milligram of chemical per kilogram of body weight per day Boxed number = Sediment concentration exceeds the respective Eco-SSL; HQ exceeds 1. NC = not a COPEC in this medium = not available						

mg/kg-day = milligram of chemical per kilogram of body weight per day
 Boxed number = Sediment concentration exceeds the respective Eco-SSL; HQ exceeds 1. NC = not a COPEC in this medium
 — = not available

7.2.4.1 UNCERTAINTIES IN EXPOSURE MODELING

Exposure modeling is a highly uncertain process throughout each step.

Estimating Exposure Concentrations. The first step in estimating uptake or intake of COPECs by representative species is determination of the exposure concentrations of COPECs. This step depends on several assumptions that create uncertainty. For the initial screening step (Tier 1), maximum concentrations of COPECs in media are used. In Tier 2, the 95 percent UCL of concentrations measured at a site are used to represent the exposure concentrations of COPECs. However, because of the relatively few surface samples collected at the site, the maximum detected concentrations of COPECs were used. Using the maximum concentration to represent exposure concentrations is very conservative. Moreover, sampling is often a targeted process; that is, areas where the highest concentrations of chemicals are suspected are often sampled, which will skew upward the chemical concentration data within the study boundaries.

Other sources of uncertainty concerning the use of the maximum COPEC concentrations as a representative EPC include chemical bioavailability and mobility. Extraction methods used to determine chemical concentrations in soil are rigorous and destructive; chemicals are often sorbed to soil particles such that they may not be available to ecological receptors under normal environmental conditions. Furthermore, chemicals, whether sorbed or free, are often mobile in soil and may migrate off site through surface water runoff or below ground via leaching; chemical concentrations measured in a single round of sampling represent a snapshot in time and may not represent persistent exposure concentrations.

All Tier 1 and Tier 2 risk estimates are based on the maximum COPEC concentration found in each medium. This overestimated exposure results in overestimated risks.

Bioconcentration Factors. The use of bioconcentration factors in exposure modeling also presents uncertainty. BCF_p values for inorganics are based on Strege and Peterson (1989), which were not peer-reviewed, and the publication cites other internal references as sources of data. K_{ow} values developed according to a regression relationship established by Travis and Arms (1988) were used to calculate BCF_p values for organics. The relationship is far from perfectly linear ($r^2=0.55$), and it is based largely on studies with pesticides. BCF_p values for organics in other chemical classes may not be accurately represented by this relationship. Moreover, BCF_p values were developed for terrestrial plants, but are also used to predict uptake of COPECs from sediment by aquatic plants. Uncertainty associated with BCF_e values extends largely from the fact that they are based on a single study for each chemical. The physical characteristics of the soil used in a study, which may affect BCF_e values, rarely match the site soil characteristics. Furthermore, the use of surrogate chemicals was required when BCF_e values were unavailable for a particular COPEC. Finally, for both BCF_p and BCF_e values, the potential for variation between species of plants and earthworms, respectively, is unaccounted for.

Species-Specific Exposure Factors. The exposure models used to predict uptake of COPECs by the house mouse, northern cardinal, and black-necked stilt via various pathways depend on species-specific exposure factors that are averages and have uncertainty associated with them. These factors include body weight; daily food and water intake; and the percentage of soil, plant, and prey material constituting the food intake. For those same three representative species, it is assumed that there is uncertainty associated with the food chain pathways, because they are dependent on BCF_p and BCF_e values. The uncertainty in the plant ingestion pathway stems from the fact that BCF_p values are not species-specific and do not differentiate between various plant "upper" parts (e.g., shoots, leaves, seeds, berries). Thus, although the receptors tend to eat different types and parts of plants, this is inconsequential in the modeling. For the prey ingestion pathway, it is assumed that an earthworm

BCF can represent the body burden of the terrestrial prey that the house mouse and the northern cardinal consume. In reality, the house mouse and the northern cardinal may eat other small animals (e.g., insects) that may bioconcentrate chemicals to a greater or lesser extent than earthworms. Similarly, the BCF_p and BCF_i are not specific for the types of plants and aquatic organisms that the black-necked stilt may consume.

Other Factors. Several other factors that the models do not account for may affect exposure of representative species. For example, any or all of the receptors may avoid contaminated areas as a response to the contamination; also, the house mouse and birds may avoid contaminated areas if there is little to forage or prey on in the areas.

7.2.4.2 UNCERTAINTIES IN THE ECOLOGICAL TOXICITY ASSESSMENT

The extrapolations required for generating TRVs from toxicity database are summarized below:

- Extrapolation of toxicity values measured in one species to other species (taxonomic extrapolation)
- Extrapolation from one toxicological endpoint to another (endpoint extrapolation)
- Extrapolation of BCF values from one chemical to another and from one taxonomic group to another (e.g., earthworm BCF assumed to be similar to BCF for other soil invertebrates)

Numerical uncertainty factors were applied when conducting some of these extrapolations. Uncertainty exists in the value of these factors, as they are not based on any scientific study but rather are conservative estimates. Regulatory guidance is provided for only some of the uncertainty factors used.

Other sources of uncertainty are present that were not dealt with using numerical uncertainty factors. For one, it has long been recognized that laboratory studies used as a basis for generating TRVs may not accurately represent the complexities of potential exposure under field conditions. In addition, some studies that were used to generate TRVs were not chronic in nature. It is difficult to interpret the potential for long-term ecological effects from acute or subchronic studies.

The studies used to support the TRV for lead ingestion demonstrated adverse effects at very low concentration in the laboratory. When these low TRVs are used to back calculate, Eco-SSL or cleanup goals as low as 0.07 mg/kg result. This concentration is three orders of magnitude below background concentrations common in soils throughout the continental United States (Connors and Shacklette 1975); therefore, the lead screening level is considered extremely conservative.

Finally, toxicological studies on which TRVs are based deal with a single chemical; effects of simultaneous exposure to multiple contaminants were not addressed.

7.2.4.3 UNCERTAINTY IN THE HAZARD QUOTIENT METHOD

The use of HQs for the assessment of risk presents some level of uncertainty. First and foremost, calculation of an HQ is based on exposure modeling and development of TRVs, two exercises that have uncertainty in and of themselves. Second, it is assumed that HQs for individual chemicals are additive. Although the endpoints measured in most toxicological studies used to generate TRVs were the same (development/reproduction/survival), the effects of simultaneous exposure to multiple contaminants may be synergistic or antagonistic (i.e., not necessarily additive).

7.2.4.4 UNCERTAINTIES ASSOCIATED WITH ECO-SSLs

Eco-SSLs are only as accurate as the exposure and toxicity information used to calculate them. Many of the uncertainties described for the exposure modeling, toxicity assessment, and HQ method also describe uncertainties associated with the Eco-SSL calculations. For example, for some chemicals, BCF_p and BCF_e data were not available. In such instances, pathways for which these variables are required to calculate exposure were not included in the chemical- and receptor-specific Eco-SSL calculations; thus, the Eco-SSLs presented may be overestimated (i.e., less conservative). However, overly conservative assumptions in the exposure assessment and the toxicity assessment (e.g., dividing toxicological benchmarks by numerical uncertainty factors) may compensate for overestimated Eco-SSLs.

7.2.4.5 UNCERTAINTIES ASSOCIATED WITH SCREENING AGAINST SURFACE WATER CRITERIA

Uncertainties in using surface water screening criteria arise due to the lack of screening criteria for many COPECs. Although three different sources were used for screening values (Hawaii Chronic WQSs, NRWQC, and Great Lakes Tier 2), there are still a number of COPECs for which there are no screening values, and therefore, risk to receptors remains uncertain.

In marine surface water, the following COPECs are without screening values:

- Benzo(a)anthracene
- Benzo(k)fluoranthene
- Dibenzo(a,h)anthracene
- Benzo(b)fluoranthene
- Chrysene
- Indeno(1,2,3)pyrene
- Benzo(g,h,i)perylene
- Di-n-octylphthalate
- Pyrene

These COPECs were all detected in the marine water samples collected at this site. Risk associated with exposure to these individual COPECs cannot be quantified for aquatic life in these surface waters.

The same uncertainties are associated with freshwater screening criteria. COPECs that were detected in fresh surface water samples but for which there are no screening criteria available are as follows:

- Benzo(a)anthracene
- Chrysene
- 2-Nitrophenol
- Benzo(b)fluoranthene
- Di-n-octylphthalate
- Phenanthrene
- Benzo(g,h,i)perylene
- Fluoranthene
- Pyrene
- Benzo(k)fluoranthene
- Indeno(1,2,3)pyrene

Risk to freshwater aquatic life associated with exposure to these individual COPECs cannot be quantified.

7.2.4.6 UNCERTAINTIES ASSOCIATED WITH SCREENING AGAINST SEDIMENT SCREENING CRITERIA

Uncertainties in using sediment screening criteria arise due to the lack of screening criteria for many COPECs.

COPECs that were detected in freshwater sediment samples but for which there are no screening criteria available are as follows:

- Acetone
- Anthracene
- BEHP
- Benzo(b)fluoranthene
- Benzo(g,h,i)perylene
- Benzo(k)fluoranthene
- 4-Bromophenyl-phenylether
- 2-Butanone
- Carbon disulfide
- Diethylphthalate
- Indeno(1,2,3)pyrene
- 2-Nitrophenol
- Phenol

Risk to freshwater benthic organisms from these COPECs cannot be quantified. However, the PAHs can be segregated into LMW and HMW groups, and the total concentrations in each molecular weight category can be compared to group screening criteria.

In marine sediment, the following COPECs are without screening values:

- Acetone
- 2-butanone
- Carbon disulfide
- Benzo(b)fluoranthene
- Benzo(g,h,i)perylene
- Benzo(k)fluoranthene
- BEHP
- 4-bromophenyl-phenylether
- Diethylphthalate
- Indeno(1,2,3)pyrene
- Phenol

These COPECs were all detected in the estuarine sediment samples taken at this site, but risk to the benthic organisms that utilize these sediments cannot be quantified. The same uncertainties are associated with estuarine sediment screening criteria as with freshwater criteria; however, there are no criteria for PAH-molecular-weight groups. In this case, the total PAH concentrations in each molecular weight group were compared to freshwater screening values. There is uncertainty in using freshwater criteria for saltwater samples.

7.2.5 Risk Characterization

The HQ methodology results in an estimate of the potential for adverse effects based on conservative assumptions. To better define the potential for adverse effects to ecological receptors, the potential for risk needs to be examined in light of the identified uncertainties.

HQ and HQ pathway sum values for each receptor at the site are presented in Appendix O.3. The risk tables also show contributions of individual chemical HQ values to each HQ_{sum}. Pathway risks are summarized in Table 7-16, Table 7-17, Table 7-18, and Table 7-19.

Table 7-16: Summary of Surface Soil Exposure Pathway HQ Values for Representative Species (Step 2)

Chemical	House Mouse ^a	Northern Cardinal ^a
Lead	6E+02	2E+02

^a Screening HQ based on maximum detected COPEC concentrations.

Table 7-17: Summary of Sediment Exposure Pathway HQ Values for Representative Species (Step 2)

Chemical	Black-Necked Stilt	
	Marine ^a	Freshwater ^a
Lead	2E+02	2E+02
BEHP	4E+00	—

^a Screening HQ based on maximum detected COPEC concentrations.

— = HQ value not above 1 in this medium

Table 7-18: Summary of Surface Water Exposure Pathway HQ Values that Exceed One for the Protection of Aquatic Life

Chemical	Aquatic Life	
	Marine ^a	Freshwater ^a
Lead	1E+01	4E+01
Benzo(a)anthracene	4E+02	NS
Benzo(a)pyrene	8E+02	NS
Fluoranthene	2E+00	1E+00
Phenanthrene	3E+00	2E+00

NS = no screening values available for COPEC in this medium.

^a Screening HQ based on maximum detected COPEC concentrations.

Table 7-19: Summary of Sediment Exposure Pathway HQ Values that Exceed One for the Protection of Benthic Organisms

Chemical	Benthic Organisms	
	Marine	Freshwater
Lead	1E+00	1E+00
Benzo(a)anthracene	—	1E+00
Benzo(a)pyrene	—	2E+00
Chrysene	—	1E+00
Pyrene	—	1E+00

Note: Screening HQ based on maximum detected COPEC concentrations.

— = HQ value not above 1 in this medium.

Risk to Ecological Receptors. HQ values for lead for the house mouse and northern cardinal exceed 1 for soil exposure pathways. HQ values for lead and BEHP for the black-necked stilt exceed 1 for sediment exposure pathways. This indicates a potential for adverse effects from exposure to site lead and BEHP contamination through the food chain. The risk to vertebrate receptors is considered unacceptable. The major risk drivers for the representative species are lead in soil and sediment and BEHP in sediment.

HQ values for aquatic organisms through surface water exposure exceed 1 for lead and four PAHs in marine surface waters, and lead and phenanthrene in fresh surface waters. One PAH (benzo(a)pyrene) in freshwater sediments shows risk to benthic organisms. Screening risk to the aquatic and benthic communities is considered unacceptable.

7.2.6 Conclusions

The quantitative effects assessment and subsequent screening risk characterization indicate the following:

- The risk to representative birds is unacceptable based on the Step 2 screening assumptions.
- The risk to representative mammals is unacceptable based on the Step 2 screening assumptions.
- The risk to aquatic life is unacceptable based on the Step 2 screening assumptions.

7.2.7 Tier 1, Step 2 Exit Criteria and Scientific/Management Decision Point

Two outcomes are possible at this point in the SERA:

1. The site passes the screening risk assessment. There is either an absence of complete exposure pathways, or all COPECs in all affected media are below screening concentrations (no HQ values exceed 1). Because of the conservative nature of the screening process, it is very unlikely that the site is a risk to ecological resources and the site is referred to No Further Action from the standpoint of ecological risk.
2. The site fails the screening risk assessment. The site must have complete exposure pathways and one or more COPECs in one or more media exceed their respective screening values (HQ exceeds 1). The evaluation proceeds to Step 3a to refine exposure assumptions to more closely reflect actual site conditions.

Although migration pathways from the EJFDF to the offsite area are considered incomplete, exposure pathways within the offsite area are complete and some of the calculated HQ values exceed 1; therefore, the evaluation of risk to wildlife is carried to Tier 2, Step 3a for further consideration.

7.3 TIER 2, STEP 3A – SITE-SPECIFIC REFINEMENT OF SCREENING ERA

A screening ecological risk assessment was prepared as part of the Phase I RI for the EJFDF area. The results indicated acceptable risk to onsite and offsite ecological receptors. The scientific/management decision point (SMDP) for the Phase I SERA indicated unacceptable uncertainty in the exposure assumptions used to assess risk to offsite receptors. The Phase II RI was conducted to remove as much of the uncertainty associated with offsite exposure pathways as possible (for both human health and ecological risk). As part of the Phase II ecological risk assessment, the new analytical data from Phase II RI was first screened against media screening values to focus on those COPECs that may represent an unacceptable risk to ecological receptors. This Tier 2 ERA further considers those COPECs and media that did not pass the Tier 1 screening process.

Step 3a in a Navy Tier 2 ERA involves refining assumptions made in Tier 1, Step 2 to arrive at a more realistic estimation of risk. This step is divided into four parts: refinement of exposure assumptions, refinement of risk calculations, refined risk characterization, and conclusions and recommendations.

7.3.1 Refinement of Exposure Assumptions

Differences between exposure assumptions made in Tier 1 and Tier 2 are summarized in Table 7-20. In general, the assumptions made in Tier 2, Step 3a are less conservative but more accurate in terms of modeling exposure and ultimately in predicting risk.

Table 7-20: Differences between Exposure Assumptions made in Tier 1 and Tier 2

Parameter	Tier 1, Step 2 Assumption	Tier 2, Step 3a Assumption
Exposure point concentration (EPC)	The maximum detected concentration of each COPEC was used.	Because of small sample size, the assumption of exposure to maximum COPEC concentrations in site media was not changed. This leads to an overestimation of risk.
Body weight	A body weight at the low-end of the species' range of body weights was used to maximize exposure estimations.	A mean body weight was used for upland species. Since young stilts may feed in the watercress paddies once they can fly, the low-end body weight was retained for the stilt exposure estimates.
Ingestion rate	An ingestion rate corresponding to the body weight was used. (Ingestion rates were derived from body weights using allometric equations.)	A mean ingestion rate was used for upland species. A maximum food intake was retained for the stilt exposure estimates.
Diet partitioning factor (PDF)	Soil, plant, and animal fractions of the diet were estimated to be 0.02, 0.5, and 0.5, respectively, for the mouse and the cardinal. These fractions total 1.02, which means effectively that 2% more than the species' total daily intake was consumed daily.	Literature-derived estimates of soil, plant, and animal fractions in the diet were used. The sum of the fractions was 1. Values are presented in Table 7-9.
Site use factor (SUF)	Assumed to be 1; species spends 100% of its time within the contaminated area.	Calculated by dividing the contaminated site area by the foraging range of the species. Due to the dispersed nature of the habitat, a SUF of 1 was used in the refinement step. This will lead to an overestimation of risk to the stilt, which has a foraging area of approximately 24 hectares.

Note: Applies to house mouse, northern cardinal, and black-necked stilt representative species.

7.3.2 Refinement of Risk Calculations

HQ values were recalculated for vertebrate representative species and all exposure pathways using the refined exposure assumptions. The results are presented in Appendix O.4 and summarized in Table 7-21 and Table 7-22. HQ values for aquatic life and benthic organisms were not included in the Tier 2 refinement step.

Table 7-21: Summary of Surface Soil Exposure Pathway HQ Values for Representative Species (Step 3a)

Chemical	House Mouse	Northern Cardinal
Lead	3E+02	1E+02

Table 7-22: Summary of Sediment Exposure Pathway HQ Values for the Black-Necked Stilt (Step 3a)

Chemical	Black-Necked Stilt	
	Freshwater	Marine
Lead	1E+02	1E+02
BEHP	—	3E+00

— = HQ value not above 1 in this medium

7.3.3 Refined Risk Characterization

Risk to Ecological Receptors. Based on the refined exposure assumptions, HQ values for the house mouse, and the northern cardinal still exceed unity for lead. The refinement did not include use of an

estimate of the upper limit mean exposure since the sample size was too small to accurately estimate a 95 percent UCL. The HQ values for the black-necked stilt still exceed 1 for both lead and BEHP, as well. The HQ values are driven by the ingestion of invertebrates both terrestrial (for the house mouse and the northern cardinal) and aquatic (for the stilt).

No refinement of the risk to aquatic life and benthic organisms was included, so the risk estimates remained the same as the Tier 1 estimates.

Phase II RI data indicate that groundwater from the caprock water-bearing zone does not discharge to surface water in the watercress farm area. In addition, caprock groundwater discharge in this area (if it were to occur) would be insignificant relative to the high volume of irrigation water flowing through the watercress fields and drainage channels. A high level of dilution is also expected if the groundwater discharges directly to Pearl Harbor. Since ecological risk for Pearl Harbor is being investigated separately, that risk is not included in this assessment. However, due to an expected high dilution factor, risk to harbor ecological receptors is expected to be acceptable.

7.3.4 Conclusions and Recommendations

Three outcomes are possible at this point in the ERA:

1. All COPECs in all affected media are below screening concentrations (no HQ values exceed 1) and uncertainties are acceptable to risk managers. It is unlikely that the site is a risk to ecological resources and the site is referred to NFA from the standpoint of ecological risk.
2. One or more COPECs in one or more media exceed their respective screening value (HQ exceeds 1). Risk managers decide (based on the risk estimates, uncertainty, and other factors) whether the site represents an unacceptable threat of adverse effects to ecological resources. If uncertainties are unacceptable, the site will be referred to a Navy Tier 2 baseline ERA that will focus on those COPECs and pathways driving risk. The purpose of the Tier 2 ERA is to reduce unacceptable uncertainties to allow risk managers to make a final decision on the potential risk to site ecological resources. The baseline risk assessment methodology is included as Steps 3 through 7 in the EPA eight-step guidance.
3. One or more COPECs in one or more media exceed their respective screening value (HQ exceeds 1). Risk managers make a decision, based on the risk estimates, uncertainty, and other factors, that further investigation is unlikely to lead to an acceptable risk level, and remediation is recommended. The revised screening levels may serve as the basis for establishing cleanup goals for the site.

Although there is unacceptable risk to ecological receptors due to the presence of lead and SVOCs in soil and surface water, the risk is overestimated because maximum detected concentrations are used to represent exposure concentrations. In addition, there is no connection between the caprock aquifer and the wetland habitat in the offsite area. Therefore, the risk associated with lead and SVOCs in the soil, water, and sediment is not associated with past fuel-handling operations at the EJFDF.

The wetland/agricultural area has been intensely developed with both dredging and filling operations common throughout the area. There are many other potential source areas, such as fill and equipment storage areas and fuel pipelines, that could contribute to the lead and SVOCs detected in the offsite area.

8. ARARs AND TBCs

Applicable or relevant and appropriate requirement (ARARs) and to-be-considered (TBC) criteria were used to assess the nature and extent of EJFDF investigation area contamination and evaluate the need for a response action. ARARs and TBCs were identified in accordance with the *Navy/Marine Corps Installation Restoration Manual* (DON 1997). According to the manual, all actions at installation restoration sites shall comply with the following:

- Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)
- Superfund Amendments and Reauthorization Act (SARA)
- National Oil and Hazardous Substances Contingency Plan (NCP)

ARARs. Section 121(d) of SARA and the NCP require that CERCLA response actions comply with federal ARARs, or state ARARs if these requirements are more stringent or site-specific than federal requirements. Under CERCLA Section 121(d)(2), federal ARARs for a remedial action may include requirements promulgated by any of the federal environmental laws (e.g., Clean Air Act [CAA], Clean Water Act [CWA], SDWA). State ARARs may include requirements promulgated under state environmental or facility siting laws that are more stringent or site-specific than federal ARARs, and that have been identified to the Navy (as the lead agency) by the state in a timely manner, according to 40 Code of Federal Regulations (CFR) 300.400(g)(4).

A requirement may be either “applicable” or “relevant and appropriate.” Applicable requirements are promulgated federal or state substantive cleanup standards, standards of control, or requirements that meet all jurisdictional prerequisites and fully address the circumstances at the site or the proposed response action. Applicable requirements are identified on a site-specific basis. To be an applicable requirement, a statute or regulation must specify the following:

- The entity subject to regulatory authority
- The types of activities that are directed or prohibited
- The substances or activities the requirement is authorized to regulate
- The time period for which the statute or regulation is in effect

Requirements that are not applicable may be relevant and appropriate. Only substantive environmental requirements from promulgated federal or state laws may be identified as relevant and appropriate. A two-step process is applied to determine whether a requirement is relevant and appropriate:

1. To determine relevance, the proposed remedial action, location, or chemicals covered by the requirement are compared with conditions at the site, release, or potential remedy. A requirement is relevant if the requirement generally pertains to these conditions.
2. To determine whether the requirement is appropriate, the comparison is further refined by focusing on the nature of the substances, the characteristics of the site, the circumstances of the release, and the proposed remedial action. The requirement is appropriate if, based on such comparisons, its use is well suited to the particular site. A facility must comply with requirements determined to be both relevant and appropriate.

The question of whether or not a requirement is relevant and appropriate is subject to professional discretion. Pertinent factors include the type of remedial actions under consideration, the hazardous

substances present, the waste characteristics, and the physical characteristics of the site. It is also possible for only part of a requirement to be considered relevant and appropriate.

To Be Considered. TBCs are non-promulgated advisories or guidance that are not legally binding, but may be used to determine cleanup levels when ARARs do not exist, or when ARARs alone would not be sufficiently protective of human health and the environment. Response actions must comply with TBCs once they are identified for a site. The selection of TBCs as performance standards, however, is discretionary and not mandatory.

Onsite/Offsite Distinction. The onsite/offsite distinction is critical for analysis of ARARs. CERCLA 121(e) exempts CERCLA response actions conducted entirely on site from all federal, state, and local permitting requirements (i.e., administrative requirements, including record keeping and reporting). Therefore, administrative requirements are not ARARs for onsite portions of a CERCLA cleanup action; only substantive requirements may be ARARs for onsite actions. For offsite cleanup actions, both substantive and administrative requirements may be ARARs. For purposes of identifying ARARs, the NCP defines an onsite response action as one where the "areal extent of contamination, and any area in very close proximity to the contamination necessary for implementation of the response action," are on site (40 CFR 300.5). For the purposes of this RI and any subsequent response action, both the EJFDF and the offsite investigation area would be considered "onsite response actions" subject to substantive requirements only.

Types of ARARs and TBCs. Potential ARAR or TBC criteria must fall into at least one of the three categories listed below to be identified as ARARs or TBCs for a specific site:

- *Chemical-specific ARARs* regulate the release of materials possessing certain chemical or physical characteristics or containing specified chemicals to the environment. These requirements generally set health- or risk-based concentration limits or discharge limits for specified hazardous substances by media. Chemical-specific ARARs are triggered by the specific chemical contaminants and environmental media found at a particular site.
- *Location-specific ARARs* govern activities in certain environmentally sensitive areas. Examples of location-specific ARARs include protective uses of floodplains, wetlands, endangered species habitat, or historically significant resources. These requirements are triggered by the particular location and the proposed activity at the site.
- *Action-specific ARARs* are restrictions that define acceptable treatment and disposal procedures for hazardous substances. These ARARs generally set performance, design, or other similar action-specific controls on particular kinds of activities related to management of hazardous substances or pollutants. Examples include the Resource Conservation and Recovery Act (RCRA) regulations for waste treatment, storage, and disposal. These requirements are usually triggered by the particular remedial actions that are selected.

ARARs and TBCs become better defined as more site-specific data become available, or when a response action is selected; therefore, identification of site-specific ARARs and TBCs is an iterative process. The following subsections evaluate criteria that were considered potential ARARs and TBCs, and identify site-specific ARARs and TBCs. The tables in Section 8.4 summarize the ARARs and TBCs identified for the EJFDF investigation area.

8.1 CHEMICAL-SPECIFIC ARARs AND TBCs

Potential chemical-specific criteria for each medium of concern at the EJFDF (soil, surface water, sediment, and groundwater) as are classified as either applicable, relevant and appropriate, or to be considered.

8.1.1 Soil

Potential chemical-specific ARAR and TBC criteria for EJFDF investigation area soil are evaluated below.

DOH Tier 1 Action Levels. DOH (1995b,c, 1996a,b) Risk-Based Corrective Action (RBCA) Tier 1 action levels for soil in areas where rainfall is less than or equal to 200 centimeters per year (cm/yr) and drinking water is not threatened were identified as TBCs. Tier 1 action levels are computer-generated default values considered "very conservative" and adequate for any impacted site, unless otherwise directed by DOH. Mean annual rainfall at the site is approximately 65 centimeters (25.5 inches). The caprock groundwater can not be considered a current or potential drinking water source due to high dissolved solids concentrations (up to 3,000 mg/L), the relatively limited saturated thickness and yield of the caprock water-bearing zone, and the relatively low permeability of the caprock. In the offsite area, neither the caprock water-bearing zone nor the confined basal aquifer are classified as drinking water sources according to the DOH report *Aquifer Identification and Classification for Oahu* (DOH 1990). The confined basal aquifer in the onsite area may be considered a drinking water source; however, as discussed in Section 3.8.2, several lines of evidence indicate that it is not affected by site contaminants:

- The basal aquifer is confined by a sequence of impermeable clay and silt.
- The potentiometric surface of the basal aquifer is considerably higher than that of the unconfined caprock water-bearing zone; any leakage through the confining strata would, therefore, be directed upward.
- Contaminants associated with the MOGAS release have not been detected in groundwater samples collected from the artesian irrigation wells that tap the confined basal aquifer immediately downgradient of the EJFDF.

EPA Region IX PRGs. EPA Region IX (1998) PRGs for soil in residential areas were identified as TBCs because humans may be exposed to investigation area soil. Unacceptable risks to human health may exist if contaminant concentrations are above the PRG criteria, which are derived from toxicity values and exposure factors. A site cleanup or response action is not required if a particular PRG concentration value is exceeded. PRG concentrations are typically used to screen pollutants, trigger further investigation, or provide initial cleanup goals.

8.1.2 Surface Water

No permanent surface water exists within the boundaries of the EJFDF; however, caprock groundwater may discharge to offsite surface water. As discussed in Section 3.8.2, Phase II RI results indicate that caprock groundwater downgradient of the site discharges directly to the harbor, but does not reach the ground surface in the offsite investigation area.

Federal NRWQC and State of Hawaii WQSs. The federal CWA National Recommended Water Quality Criteria (NRWQC) (40 CFR Part 131) and the DOH WQSs (HAR Title 11-54) were evaluated as potential chemical-specific ARAR or TBC criteria for surface water. NRWQC for protection of aquatic life are based on both acute and chronic toxicity data for freshwater and marine

environments. NRWQC for protection of human health identify protective levels related to two routes of exposure:

- Drinking the water and consuming aquatic organisms, primarily fish
- From fish consumption alone

Federal NRWQC are non-enforceable guidelines, unless they are used by the state to establish WQSS. The State of Hawaii has used NRWQC to develop numerical WQSS based on use classification. Therefore, federal freshwater chronic NRWQC are considered relevant and appropriate for surface water in the investigation area. State freshwater chronic WQSS were also identified as relevant and appropriate, because they represent site-specific adaptations of the NRWQC.

Great Lakes Tier II Screening Criteria. Hawaii DOH chronic WQSS and federal NRWQC values for the protection of aquatic life were used as primary criteria to screen surface water COPEC concentrations. If neither state nor federal criteria were available, Great Lakes Tier II values presented in Suter and Tsao (1996) were used as tertiary screening values. The Great Lakes Tier II Screening Criteria were identified as TBC criteria.

8.1.3 Sediment

Potential chemical-specific ARAR and TBC criteria for sediment in the offsite agricultural and wetlands area are discussed below.

Ecotox Thresholds. EPA has identified criteria presented in *Incidence of Adverse Biological Effects Within Ranges of Chemical Concentrations in Marine and Estuarine Sediments* (Long et al. 1995) as emergency response ecotox thresholds. These ecotox thresholds give risk-based screening values for SVOCs and metals in marine and estuarine sediments, and were used as TBCs for a screening-level ecological risk assessment. Levels are based on a biological effects database that excludes freshwater data. Three sets of sediment criteria are presented:

- Sediment Quality Criteria (SQC)
- Sediment Quality Benchmarks (SQBs)
- Effects Range–Low (ER-L) and Effects Range–Medium (ER-M) values

ER-Ls and ER-Ms are based on data from 89 publications regarding chemical concentrations in sediment and the resulting biological effects (Long et al. 1995). Concentrations below ER-L values are believed to produce minimal effects in marine and estuarine biological receptors, whereas concentrations equal to or above the ER-L but below the ER-M occasionally produce adverse effects. Concentrations equal to and above the ER-M are believed to frequently produce adverse effects.

Threshold Effect Levels. TELs identified in *A Preliminary Evaluation of Sediment Quality Assessment Values for Freshwater Ecosystems* (Smith et al. 1996) were used as TBCs to screen ecological risks associated with freshwater sediments in the investigation area. Smith et al. developed sediment quality criteria for trace metals, PAHs, PCBs, and pesticides by reviewing data from numerous modeling, laboratory, and field studies. Two sets of criteria were developed: TELs and probable effect levels (PELs). The criteria define three ranges of chemical concentrations: those that were (1) rarely, (2) occasionally, and (3) frequently associated with adverse biological effects. Smith et al. found that TELs were more reliable for risk assessment purposes than PELs.

8.1.4 Groundwater

Potential chemical-specific ARAR and TBC criteria for investigation area groundwater are evaluated below.

Federal Maximum Contaminant Levels. SDWA primary MCLs (40 CFR Part 141.11–16, 141.61–62) were identified as relevant and appropriate for the confined basal groundwater beneath the site, but they were not identified as ARARs for caprock groundwater in the investigation area. Although the confined basal aquifer in the onsite area may be considered a drinking water source, several lines of evidence indicate that site contaminants do not impact the confined basal aquifer (see Section 3.8.2). The caprock water-bearing zone does not currently supply drinking water for human consumption, and, as described below, can not be considered a potential underground source of drinking water (USDW); therefore, the SDWA MCLs were not identified as ARARs for the caprock groundwater.

Characteristics of the caprock groundwater water-bearing zone that would adversely affect its use as a source of drinking water include:

- High dissolved solids concentrations (up to approximately 3,000 mg/L)
- The relatively limited yield and saturated thickness of the caprock water-bearing zone
- The low permeability of the caprock strata

EPA's definitions of an USDW, and "public water system," promulgated pursuant to the Safe Drinking Water Act (SDWA[DB1]) under the federal underground injection control (UIC[DB2]) program (see 40 CFR 144.3 and 141.2, respectively) were reviewed to evaluate MCLs as potential ARARs for the caprock groundwater.

EPA's *Guidelines for Ground-Water Classification Under the EPA Ground-Water Protection Strategy* (June 1988) recommend that an aquifer should be considered a potential drinking water source if total dissolved solids (TDS[DB3]) values are below 10,000 mg/L and the aquifer yields at least 150 gallons/day. However, the EPA groundwater classification guidelines give TBC criteria only, and are not ARARs, whereas the UIC program definition of a USDW may be considered an ARAR. The USDW definition may be considered "relevant and appropriate" in that it is "promulgated under federal environmental laws that address problems or situations sufficiently similar to those encountered at the CERCLA site" (see 40 CFR 300.5). It is emphasized that the goal of the UIC program—to protect USDWs from contamination—is consistent with the goal of CERCLA. The MCL drinking water standards (which cannot be considered ARARs for a groundwater body that is not a USDW) are promulgated under the SDWA; therefore, it is also reasonable to use the definition of a USDW promulgated pursuant to this Act. Site observations and well monitoring data collected at the EJFDF indicate that the caprock groundwater is not a potential USDW as defined in the UIC program regulations.

In 40 CFR Part 144.3, a USDW is defined as "an aquifer or its portion which contains a sufficient quantity of groundwater to supply a public water system and either currently supplies drinking water for human consumption or contains less than 10,000 mg/L total dissolved solids." In 40 CFR 141.2, a "public water system" is defined as a system that "has at least fifteen service connections or regularly serves an average of at least twenty-five individuals daily at least 60 days out of the year." The Navy estimates that minimum water demand for 25 individuals is approximately 1,250 gallons/day (based on EPA [1975] guidance, *Manual of Individual Water Supply Systems*). The

caprock water-bearing zone at the EJFDF is not likely to sustain this yield requirement without further degradation (e.g., saltwater intrusion); therefore, it does not meet the definition of a USDW.

Furthermore, the caprock water-bearing zone does not meet the definition of a USDW because it should not be considered an "aquifer or its portion." Freeze and Cherry (1979) define an aquifer as "a saturated, permeable, geologic unit that can transmit significant quantities of water under ordinary hydraulic gradients." The caprock water-bearing zone is better described as an "aquitard," which Freeze and Cherry define as less permeable beds that "may be permeable enough to transmit water in quantities that are significant in the study of regional groundwater flow, but their permeability is not sufficient to allow the completion of production wells within them."

It is also important to note that DOH technical guidance clearly indicates that the State of Hawaii does not consider the shallow caprock groundwater beneath the EJFDF to be a suitable source of drinking water. According to the DOH (1995a) technical guidance manual *Determination of Groundwater Utility at Leaking Underground Storage Tank Sites*, "recommended cleanup criteria at leaking UST sites depend on whether the groundwater underlying the site is used or intended for use as a drinking water source." The guidance manual recommends use of the DOH report *Aquifer Identification and Classification* (DOH 1990) to determine groundwater utility. In the offsite area downgradient of the EJFDF, the *Aquifer Identification and Classification* guidance classifies the caprock water-bearing zone as "unconfined, sedimentary" and "ecologically important." The classification guidance clearly does not identify the caprock groundwater as a source of drinking water. The technical guidance manual specifically notes that many of the leaking UST sites in Hawaii overlie "clay-rich, caprock coastal plain sediments that are not suitable as sources of drinking water." The EJFDF is a classic example of such a site.

SDWA MCL Goals. MCL goals (MCLGs) (40 CFR Part 141.50-.51) are non-enforceable health goals for public water systems, and represent contaminant concentrations that would result in no adverse health effects with an adequate margin of safety. Non-zero MCLGs are relevant and appropriate to the basal groundwater beneath the site. However, MCLGs are not ARARs for the caprock groundwater because the caprock water-bearing zone cannot be considered a USDW. The MCLGs were also evaluated to determine whether they represent TBC criteria. According to the *CERCLA Compliance with Other Laws Manual* (EPA 1988a), TBCs are *non-promulgated* advisories or guidance issued by federal or state government that are not legally binding, and do not have the status of potential ARARs. MCLGs are promulgated criteria; therefore, they cannot be considered TBCs.

SDWA Secondary MCLs. Secondary MCLs (SMCLs) (40 CFR Part 143.3) provide guidelines that address contaminants that may adversely affect the aesthetic quality of drinking water (taste, odor, color, appearance), and may deter public acceptance of drinking water provided by public water systems. SMCLs are relevant and appropriate for the basal groundwater beneath the site. However, SMCLs are not ARARs for the caprock groundwater because the caprock water-bearing zone cannot be considered a USDW. In addition, SMCLs are promulgated criteria; therefore, they cannot be considered TBCs.

Threshold Odor Concentrations. Non-promulgated threshold odor concentrations and taste thresholds, which are based on McKee and Wolf (1963), provide criteria to define the acceptability of a domestic water supply, and were evaluated as potential TBCs for groundwater. The threshold odor concentrations were identified as TBC for the onsite basal groundwater. However, as discussed above, the caprock groundwater is not a current or potential future source of drinking water; therefore, these criteria are not TBCs for the caprock water-bearing zone.

State MCLs. The DOH has identified MCLs (HAR Title 11-20) to protect public drinking water supply systems in the State of Hawaii. Like the federal MCLs, state MCLs are not considered applicable or relevant and appropriate to the caprock water-bearing zone. State primary MCLs more stringent than federal MCLs would be relevant and appropriate to the onsite confined basal aquifer if it was impacted by contaminants with more stringent requirements. However, none of the three contaminants with state MCLs more stringent than their federal counterparts (dibromochloropropane, ethylene dibromide, and 1,2,3-trichloropropane) have been detected in any groundwater samples collected from either the confined basal aquifer or the caprock water-bearing zone in the investigation area. Therefore, state MCLs are not ARARs for either the caprock or basal groundwater.

Federal NRWQC and State of Hawaii WQSS. Federal NRWQC and Hawaii chronic WQSSs for marine aquatic life were evaluated as potential ARAR and TBC criteria for the caprock water-bearing zone because hydrogeologic evidence suggests that caprock groundwater discharges to the Middle Loch of Pearl Harbor. (However, May 1999 groundwater sampling data indicates that the core of the caprock groundwater BTEX plume is at least 1,000 feet upgradient of the Middle Loch shoreline [approximately 100 feet downgradient of UST S-26].) Federal NRWQC are nonenforceable guidelines, unless they are used by the state to establish WQSSs. The State of Hawaii has used NRWQC to develop numerical WQSSs based on use classification. Therefore, federal marine NRWQC were identified as relevant and appropriate criteria for the caprock water-bearing zone and for the confined basal aquifer in the offsite investigation area. State chronic marine WQSSs were also identified as relevant and appropriate for these two water-bearing units because they represent site-specific adaptations of the federal NRWQC.

DOH Tier 1 Action Levels. DOH (1995b,c, 1996a,b) Corrective Action and Decision Making Tier 1 Guidelines for groundwater in areas where rainfall is less than or equal to 200 cm/yr and drinking water is not threatened were identified as TBCs for the caprock groundwater. The caprock groundwater can not be considered a current or potential drinking water source due to high dissolved solids concentrations (up to 3,000 mg/L), the limited saturated thickness of the caprock water-bearing zone, and the relatively low permeability of the caprock. In the offsite area, neither the caprock water-bearing zone nor the confined basal aquifer are classified as drinking water sources according to the report *Aquifer Identification and Classification for Oahu* (DOH 1990). In addition, although the confined basal aquifer in the onsite area may be considered a drinking water source, several lines of evidence indicate that site contaminants do not impact the confined basal aquifer (see above and Section 3.8.2).

Hawaii Water Quality Antidegradation Policy. This policy (HAR Title 11-54-01.1) states that "Waters whose quality are higher than established water quality standards shall not be lowered in quality unless it has been affirmatively demonstrated to the director that the change is justifiable as a result of important economic or social development and will not interfere with or become injurious to any assigned uses made of, or presently in, those waters." Hydrocarbons associated with the 1971 MOGAS release were detected in onsite caprock groundwater; however, spatial data trends indicate that the concentrations of these contaminants reach negligible levels well inland of Pearl Harbor. Contamination associated with the EJFDF, therefore, does not degrade water quality in Pearl Harbor. Consequently, the Antidegradation Policy is not an ARAR.

8.2 LOCATION-SPECIFIC ARARs AND TBCs

The criteria listed below were evaluated as potential location-specific ARAR and TBC criteria for the EJFDF investigation area.

Hawaii Coastal Zone Management Law. Section 307(c)(1) of the Coastal Zone Management Act, 16 United States Code (USC) 1451 requires federal agencies to conduct or support activities that may directly affect the coastal zone in a manner consistent with approved state coastal zone management programs such as the Hawaii Coastal Zone Management Law (HCZM). The HCZM would be applicable only if a response action that would directly affect the coastal zone is implemented at the site. The HCZM requires preservation of historic, scenic, open space and marine resources, coastal ecosystems, beaches, and recreation areas. Although CERCLA onsite actions are not subject to administrative review, the lead agency is required to ensure that such actions comply with the substantive requirements of the state's coastal zone management plan and should prepare an analysis to document compliance.

Endangered Species Act. The Endangered Species Act (ESA) requires protection of proposed and listed endangered and threatened species, and critical habitats upon which these species depend. As discussed in Section 3.3, no plant species listed as rare, threatened, or endangered have been observed at the EJFDF or in the offsite area. Due to the disturbed conditions, no listed plant species are expected. No rare, threatened, or endangered animal species have been observed on site at the EJFDF, and none are expected due to the extensive non-native vegetation. However, endangered water birds were observed in the offsite agricultural and wetlands area during the 1998 ecological survey; therefore, the ESA was identified as applicable to the offsite investigation area.

8.3 ACTION-SPECIFIC ARARs AND TBCs

Action-specific ARARs or TBCs are not usually identified during the scoping or site characterization phase of a RI, but may be identified during later phases, or as required for subsequent response action. EJFDF activities are currently in the site-characterization phase; therefore, well construction requirements were the only action-specific criteria evaluated for the Phase II RI.

Hawaii Well Construction Standards. The Hawaii Well Construction Standards (HWCS) (HAR 13-168-14) establish minimum standards to ensure safe and sanitary maintenance and operation of water wells and prevent contamination of groundwater. EJFDF monitoring wells are water wells as defined in HAR Section 13-168-2; therefore, the HWCS criteria are applicable. (The HAR Section 13-168-2 definition of water wells includes borings drilled for exploration of groundwater.)

8.4 CONCLUSIONS

Identification of site-specific ARARs and TBCs is an iterative process. The requirements become better defined as more site-specific data become available, or when a response action is selected. This iteration presented in this report identified the criteria listed in Tables 8-1 through 8-3 as either applicable, relevant and appropriate, or to-be-considered.

Table 8-1: Chemical-Specific ARARs and TBCs for the EJFDF Investigation Area

Criteria	Description	Discussion	Applicable, Relevant and Appropriate, or TBC
Soil			
Hawaii Department of Health (DOH) Risk-Based Corrective Action (RBCA) Tier 1 Action Levels (DOH 1995b,c, 1996a,b)	Chemical-specific DOH-recommended criteria for soil contaminant concentrations.	Tier 1 action levels for soil and groundwater are dependent on two site characteristics: groundwater utility and annual rainfall. Tier 1 criteria for soil in areas where drinking water is not threatened and rainfall is less than or equal to 200 cm/yr were identified as TBCs.	TBC
EPA Region IX Preliminary Remediation Goals (PRGs) (EPA Region IX 1998)	Chemical-specific human health risk-based screening criteria. Levels are based on current EPA toxicological and risk assessment data.	EPA Region IX PRGs for residential soil were identified as TBCs for chemical-specific health risk screening. (DOH Tier 1 action levels were used as screening criteria for TPH.)	TBC
Surface Water			
Federal Clean Water Act, National Recommended Water Quality Criteria (NRWQC) (40 CFR Part 131)	Sets chemical-specific criteria for surface water quality based on toxicity to humans and aquatic organisms. NRWQC are not enforceable unless used by the state for establishing WQSS.	Watercress farm surface water discharges to the Middle Loch of Pearl Harbor. Because Hawaii has used the federal NRWQC in setting WQSS, the NRWQC were identified as relevant and appropriate.	Relevant and appropriate
Hawaii DOH Water Quality Standards (WQSS) (HAR Title 11-54)	Sets chemical-specific criteria for surface water quality based on toxicity to humans and aquatic organisms. State criteria are a site-specific adaptation of federal NRWQC.	Watercress farm surface water discharges to the Middle Loch of Pearl Harbor. State WQSS were identified as relevant and appropriate because they represent site-specific adaptations of the NRWQC.	Relevant and appropriate
Great Lakes Tier II Screening Criteria (Suter and Tsao 1996)	The Great Lakes Tier II screening criteria address toxicity to aquatic organisms in surface water.	Hawaii DOH chronic WQSS and federal NRWQC values for the protection of aquatic life were used as primary criteria to screen surface water COPEC concentrations. The Great Lakes Tier II Screening Criteria were used as TBC criteria if neither state nor federal criteria were available.	TBC
Sediment			
EPA Office of Solid Waste and Emergency Response Ecotox Thresholds (Long et al. 1995)	ER-L and ER-M criteria from the ecotox thresholds give screening values for SVOCs and metals in marine and estuarine sediments. The levels are based on a biological effects database that excludes freshwater data.	ER-Ls and ER-Ms are not cleanup levels, but can be used as screening tools to evaluate ecological threats posed by contaminated marine sediments.	TBC
Threshold Effect Levels (TELs) (Smith et al. 1996)	TELs give screening values for trace metals, PAHs, PCBs, and pesticides in freshwater sediments. TELs are based on data from numerous modeling, laboratory and field studies.	TELs are not cleanup levels, but can be used as screening tools to evaluate ecological threats posed by contaminated freshwater sediments.	TBC

Criteria	Description	Discussion	Applicable, Relevant and Appropriate, or TBC
Groundwater			
Safe Drinking Water Act (SDWA) Maximum Contaminant Levels (MCLs), secondary MCLs (SMCLs), and non-zero MCL goals (MCLGs) (40 CFR Part 141.11–.16, 141.61–.62)	MCLs are drinking water standards that apply to contaminants EPA has determined may adversely affect human health. Each contaminant's MCL is set as close as feasible to the MCLG for that contaminant (see below), while also considering the technical and economic feasibility of removing the contaminant from the water supply. SMCLs are non-enforceable aesthetic (taste, odor, color) criteria.	Federal MCLs are applicable to water systems at the tap, and, together with SMCLs and non-zero MCLGs, are relevant and appropriate as in-situ cleanup standards for groundwater that is or may be used as drinking water. MCLs, SMCLs, and non-zero MCLGs are relevant and appropriate to the onsite basal groundwater, but are not ARARs for caprock groundwater at the EJFDF because the caprock water-bearing zone cannot be considered a potential source of drinking water, and caprock groundwater does not impact the confined basal aquifer (the main USDW for the island).	Not ARAR for caprock groundwater beneath the EJFDF or the offsite investigation area. Relevant and appropriate for basal groundwater beneath the EJFDF and the offsite investigation area
Threshold Odor Concentrations and Taste Thresholds (McKee and Wolf 1963)	Non-promulgated threshold odor concentrations and taste thresholds provide criteria to define the acceptability of a domestic water supply.	The caprock water-bearing zone is not a current or potential future source of drinking water; therefore, these criteria are not TBCs for the caprock water-bearing zone.	Not TBCs for caprock groundwater beneath the EJFDF or the offsite investigation area TBC for basal groundwater beneath the site
Clean Water Act Marine NRWQC (40 CFR Part 131)	Sets contaminant-specific criteria for marine surface water quality based on toxicity to aquatic organisms and human health.	Caprock groundwater discharges to the Middle Loch of Pearl Harbor. Because Hawaii has used the federal marine NRWQC in setting marine chronic WQSS, the marine NRWQC were identified as relevant and appropriate.	Relevant and appropriate
Hawaii DOH Marine Chronic WQSS (HAR Title 11-54)	Sets contaminant-specific criteria for surface water quality based on toxicity to marine aquatic life. The marine chronic WQSS are site-specific adaptations of federal marine NRWQC.	Caprock groundwater discharges to the Middle Loch of Pearl Harbor. Therefore, Hawaii marine chronic WQSS were identified as relevant and appropriate. Also relevant and appropriate to basal groundwater in the offsite investigation area	Relevant and appropriate
Hawaii DOH Corrective Action and Decision Making Tier 1 Guidelines (DOH 1995b,c, 1996a,b)	Chemical-specific DOH-recommended criteria for groundwater contaminant concentrations.	Tier 1 action levels for soil and groundwater are dependent on two site characteristics: groundwater utility and annual rainfall. Tier 1 criteria for those chemicals in groundwater without ARARs in areas where drinking water is not threatened and rainfall is less than or equal to 200 cm/yr were identified as TBCs.	TBC

Table 8-2: Location-Specific ARARs and TBCs for the EJFDF Investigation Area

Criteria	Description	Discussion	Applicable, Relevant and Appropriate, or TBC
Hawaii Coastal Zone Management Law (HCZM) (Hawaii Revised Statutes [HRS] Chapter 205A)	The HCZM requires preservation of historic, scenic, open space and marine resources, coastal ecosystems, beaches, and recreation areas.	The federal Coastal Zone Management Act requires federal agencies to comply with approved state coastal zone management programs, such as the HCZM. The HCZM would be applicable only if a response action that would directly affect the coastal zone is implemented.	Applicable if a response action would directly affect the coastal zone
Endangered Species Act (ESA) (16 USC 1531 et seq., 50 CFR 200 and 402)	The ESA requires protection of proposed and listed endangered and threatened species, and critical habitats upon which these species depend.	Endangered water birds were observed in the offsite agricultural and wetlands area during the 1998 ecological survey; therefore, the ESA was identified as applicable.	Applicable for response action in the offsite investigation area

Table 8-3: Action-Specific ARARs and TBCs for the EJFDF Investigation Area

Criteria	Description	Discussion	Applicable, Relevant and Appropriate, or TBC
Hawaii Well Construction Standards (HWCS) (HAR 13-168-14)	The HWCS establishes minimum standards to ensure safe and sanitary maintenance and operation of water wells, and prevent contamination of groundwater.	Monitoring wells are water wells as defined in HAR Section 13-168-2; therefore, wells constructed or abandoned in the investigation area must comply with the substantive requirements of the HWCS.	Applicable

9. CONCLUSIONS AND RECOMMENDATIONS

9.1 NATURE AND EXTENT OF CONTAMINATION

Hydrogeologic evidence and analytical data collected during the Phase II RI indicate the presence of at least two contaminant sources:

- Residual onsite subsurface petroleum contamination from the 1971 MOGAS release
- The source (or sources) of the heavy-end hydrocarbons and lead detected in offsite surface samples

Contamination associated with the MOGAS release has remained almost completely within the EJFDF site boundary. Phase II RI sampling results indicate that MOGAS constituents have not reached the offsite area at significant concentrations. MOGAS constituents detected on site consist of light-end hydrocarbons commonly found in gasoline products, such as BTEX compounds, 1,2-DCA, and phenolic and naphthalene compounds in the C2–C12 hydrocarbon range. Lead levels in onsite subsurface soils and caprock groundwater are very low.

The contaminants detected offsite are primarily heavier-end PAHs in the C16–C22 hydrocarbon range, BEHP, and lead. These contaminants are commonly found in urban environments, and appear to be uniformly distributed at low levels in offsite surface soil, surface water, and sediment. Sources may include vehicle exhaust, surface runoff from Waiawa Road and other asphalt-paved roads, and water from storm sewers in the offsite area. VOCs (such as acetone, 2-butanone, and carbon disulfide [common laboratory reagents]) were detected at low levels in samples from throughout the investigation area, and are not expected to be related to an environmental source. BEHP is also a common laboratory contaminant. Therefore, these offsite contaminants are not related to the 1971 MOGAS release.

9.1.1 Offsite Surface Soil, Sediment, and Surface Water

The gasoline hydrocarbons observed in onsite soil and caprock groundwater (VOCs and light-end SVOCs) were not detected in offsite sediments, surface water, or surface soil (surface media). The only VOCs found in sediment samples were acetone, 2-butanone, and carbon disulfide, which were detected at very low levels. The SVOCs detected in offsite surface media were primarily heavy-molecular-weight PAHs and BEHP, with phenol and nitrophenol detected at very low levels in two sediment and unfiltered surface water samples. The sediment screening criteria for lead and heavy-molecular-weight PAHs were exceeded in several sediment samples; therefore, these contaminants were evaluated in the human health and ecological risk assessments. The heavy-molecular-weight PAHs and phthalates detected in offsite surface media are common urban contaminants associated with vehicle exhaust and runoff from asphalt-paved roads, and are uniformly distributed across the offsite area. Because of their high boiling points, they are not found in gasoline products; therefore, these contaminants are not likely to be related to the residual onsite MOGAS contamination. Lead concentrations detected in the offsite surface media were much higher than lead concentrations detected in subsurface soil and groundwater. This indicates that lead in the offsite surface media is attributable to offsite surface sources, and is not associated with the MOGAS release.

9.1.2 Offsite Subsurface Soil

Very low levels (well below risk-based screening criteria) of contaminants that may be associated with MOGAS (such as TPH-gasoline, ethylbenzene, trimethylbenzenes, and total xylenes) were detected in subsurface soil samples collected along Waiawa Road just south of the site boundary, in the western portion of the offsite area. These subsurface soil samples were collected downgradient of an

underground petroleum pipeline that parallels the southern boundary of the EJFDF; therefore, a pipeline leak may be the source of this contamination. Light-end SVOCs and BEHP, which were detected in onsite caprock groundwater, were also detected at low levels in several offsite subsurface soil samples. Heavy-end PAHs, which were not detected in onsite caprock groundwater, were also detected in several subsurface soil samples. Lead concentrations detected in offsite subsurface soils were very low. Similar low lead levels were detected in onsite subsurface soil samples collected for the Phase I RI (Ogden 1996). No subsurface soil contaminants were detected at levels above EPA Region IX residential soil PRGs. The subsurface soil data indicate that MOGAS constituents from the EJFDF have not migrated significantly beyond the site boundary, and are not likely to threaten human health.

9.1.3 Groundwater

Data from two rounds of Phase II RI caprock groundwater sampling show that concentrations of MOGAS constituents (such as BTEX and 1,2-DCA) have significantly decreased over the 5 years since the last Phase I RI sampling round. Although very low concentrations of toluene and 1,2-DCA were detected in two offsite wells immediately south of the EJFDF boundary during the first groundwater sampling round, virtually all MOGAS-related contamination has remained on site. Except for acetone, no VOCs were detected in any of the samples collected from offsite caprock groundwater during round two sampling (April–May 1999). Light-end SVOCs potentially related to the onsite residual MOGAS contamination were detected in several offsite caprock groundwater samples; however, the offsite concentrations were well below Hawaii WQs and Hawaii Tier 1 action levels.

Heavy-end PAHs were detected during the first round at very low levels (below MRLs) in one onsite duplicate groundwater sample from MW-4, and one offsite groundwater sample from MW-26. Because of their high boiling points and low frequency of occurrence, these heavy-end PAHs are not associated with onsite MOGAS contamination. Heavy-end PAHs were not detected in any of the caprock groundwater samples collected during the second round of groundwater monitoring. BEHP was detected in onsite and offsite monitoring well samples collected during both sampling rounds. Relatively high BEHP concentrations were reported for groundwater samples collected from several onsite wells during the first round; however, the high BEHP levels were attributed to contamination introduced at the analytical laboratory.

Lead was detected at very low levels in caprock groundwater, except in offsite microwells where the high turbidity of the unfiltered samples resulted in higher concentrations of lead and other heavy metals. Lead and the other priority pollutant metals detected in caprock groundwater are not associated with the onsite residual MOGAS contamination.

Groundwater samples were collected from the flowing artesian wells screened in the deep, confined basal aquifer. Concentrations of MOGAS-related contaminants were below health-based screening criteria (MCLs for drinking water). Hydrogeologic constraints prevent residual onsite MOGAS contaminants in caprock groundwater from migrating downward to the basal aquifer.

9.2 CONTAMINANT FATE, TRANSPORT, AND OFFSITE EXPOSURE PATHWAYS

The caprock water-bearing zone represents the only significant pathway for transport of residual onsite MOGAS contaminants. The reduction in BTEX and 1,2-DCA concentrations with both time and distance downgradient of the source area, coupled with the distribution and concentration of electron acceptors relative to the BTEX plume, provides very strong evidence of the following:

- Natural attenuation of dissolved hydrocarbons in caprock groundwater has been occurring.
- Contaminant concentrations will continue to decrease in the future.

As discussed in Section 9.1, the Phase II RI has identified at least two contaminant sources:

- Onsite residual subsurface contamination from the 1971 MOGAS release
- Offsite contamination from sources that may include vehicle exhaust, surface runoff from Waiawa Road and other asphalt-paved roads, and water from storm sewers in the offsite area

There is no complete pathway for transport of aqueous-phase MOGAS hydrocarbons in caprock groundwater to human receptors in the offsite watercress farm area. Hydrogeologic evidence and analytical data indicate that caprock groundwater discharges to Pearl Harbor—not to the agricultural area. In addition, the data indicate that the dissolved hydrocarbons are naturally attenuating, and that virtually all MOGAS-related contamination has remained on site over the 28 years since the MOGAS release.

9.3 OFFSITE HUMAN HEALTH PRELIMINARY RISK EVALUATION

A human health PRE was conducted to assess risks to human health associated with the residual onsite MOGAS contamination that exists at the EJFDF. The PRE was based on analytical data collected during the Phase II RI. PRE findings were used to evaluate the need for further response action at the EJFDF. Onsite human health risks were addressed in the Phase I RI (Ogden 1996).

As noted above, there are no transport pathways that would expose offsite human receptors to the remaining onsite MOGAS contamination. For offsite contaminants not related to the 1971 MOGAS release, the human health PRE indicates no significant threat to offsite residents, farm workers, and utility workers.

9.4 OFFSITE SCREENING ECOLOGICAL RISK EVALUATION

The Phase II RI biological survey identified several endangered bird species in the offsite investigation area, including the Hawaiian common moorhen (*Gallinula chloropus sandvicensis*), Hawaiian black-necked stilt (*Himantopus mexicanus knudseni*), Hawaiian coot (*Fulica alai*), and Hawaiian duck (*Anas wyvilliana*). The watercress farmers have observed the endangered short-eared owl (*Asio flammeus sandwichensis*) flying in the area at dusk. The intended purpose of the ERA was to expand upon the Phase I RI (Ogden 1996) ecological risk assessment findings by evaluating potential offsite ecological impacts related to the residual onsite MOGAS contamination. As such, the Phase II ERA covered a screening ERA Navy Tier I (EPA Steps 1–2) and portions of a baseline ERA in Tier II (EPA Steps 3a). The Phase II ERA findings were used to evaluate the need for further response action at the EJFDF. Another Navy study (the Pearl Harbor Sediment Study [Ogden, in-progress]) is addressing exposure to ecological receptors in Pearl Harbor. Onsite exposure pathways were addressed in the Phase I RI report (Ogden 1996).

The ERA assessed risks to ecological receptors associated with direct contact with offsite surface soil, sediment, and surface water. No transport pathways would expose ecological receptors in the watercress farm area to the residual onsite MOGAS contamination. Ecological risk drivers (lead and heavy PAHs) in the offsite surface media are not associated with the residual onsite MOGAS contamination. The ERA followed a two-tiered screening approach based on EPA guidance (EPA 1997a), and included an additional screening step based on Navy guidance (DON 1999). The Phase II ERA concluded that: (1) there are no complete offsite exposure pathways for EJFDF contaminants; and (2) maximum non site-related lead and SVOC concentrations in surface water and soil may pose unacceptable risks to terrestrial (both house mouse and northern cardinal) and aquatic (black-necked stilt) receptors in the offsite wetland area. These risks are likely

overestimated, because they are based on exposure to maximum detected lead and SVOC concentrations.

9.5 RECOMMENDATIONS

Maximum groundwater hydrocarbon concentrations detected during the Phase II RI are below chemical-specific ARAR and TBC criteria identified for the caprock water-bearing zone. Federal marine NRWQC and more stringent Hawaii marine chronic marine WQs, which were developed for protection of aquatic organisms and human health, are ARARs. For those groundwater chemicals without ARARs, Hawaii Tier I action levels for sites where drinking water sources are not threatened, which are based on federal WQC, are TBCs. DOH UST guidance describes caprock water-bearing zones on Oahu as potential water-bearing zones with little human health significance. Because of its high salinity (TDS up to 3,000 mg/L) and insufficient yield for a public water system, the caprock groundwater is not a current or potential future underground drinking water source. In addition, dissolved hydrocarbons in the caprock groundwater cannot migrate to the underlying confined basal aquifer. The hydraulic gradient across the low-permeability confining strata between the caprock water-bearing zone and the confined basal aquifer is directed upward, preventing caprock groundwater contaminants from migrating downward to the confined basal aquifer. Because the caprock groundwater is not a potential underground drinking water source and has no impact on a drinking water source, EPA SDWA MCLs, SMCLs, and non-zero MCLGs are considered neither applicable nor relevant and appropriate for the caprock groundwater.

An extensive body of groundwater monitoring data indicates that natural attenuation has greatly reduced caprock groundwater hydrocarbon concentrations over the 28 years since the MOGAS release, and will continue to reduce hydrocarbon concentrations. Phase II RI findings and risk assessment results provide strong evidence that remaining onsite MOGAS constituents pose no significant human health or ecological threats, and maximum detected caprock groundwater concentrations of chemicals potentially related to the MOGAS release are now below ARAR and TBC criteria. Therefore, based on the combined Phase I and Phase II RI findings, no further action is recommended for the EJFDF.

10. REFERENCES

- Adriano, D. C. 1986. *Trace Elements in the Terrestrial Environment*. New York: Springer-Verlag.
- Agency for Toxic Substances and Disease Registry (ATSDR). 1992. *Toxicological Profile for 1,2-Dichloroethane*. Draft Update. U.S. Department of Health and Human Services. October.
- . 1993. *Toxicological Profile for Polycyclic Aromatic Hydrocarbons (PAHs)*. Draft. U.S. Department of Health and Human Services.
- American Mathematical Society. 1975. *Mathematical Statistics, Vol. III*. Providence, R.I.: Institute of Mathematical Statistics.
- Bent, A. C. 1962. *Life Histories of North American Shore Birds*. Part 1. New York: Dover.
- Beyer, W. N., E. E. Connor, and S. Gerould. 1994. Estimates of Soil Ingestion by Wildlife. *J. Wildl. Manage.* 58(2): 375–382.
- Beyer, W. N., and C. Stafford. 1993. Survey and Evaluation of Contaminants in Earthworms and in Soils Derived from Dredged Material at Confined Disposal Facilities in the Great Lakes Region. *Environ. Monitor. Assess.* 24:151–165.
- Brewer, R. 1955. Size of Home Range in Eight Bird Species in a Southern Illinois Swamp Thicket. *Wilson Bull.* 67:140–141.
- Burt, W. H., and R. P. Grossenheider. 1980. *A Field Guide to the Mammals*. 3rd ed. Boston: Houghton Mifflin.
- Buscheck, T. E., and C. M. Alcantar. 1995. Regression Techniques and Analytical Solutions to Demonstrate Intrinsic Bioremediation. In: *Proceedings of the 1995 Battelle International Conference on In Situ and On Site Bioreclamation*. April.
- California Department of Toxic Substances Control (California DTSC). 1996. *Guidance for Ecological Risk Assessment at Hazardous Waste Sites and Permitted Facilities, Part A: Overview*. 4 July. Human and Ecological Risk Division.
- Callahan, M. A., et al. 1979. *Water Related Environmental Fate of 129 Priority Pollutants*. Prepared for U.S. EPA Office of Water Planning and Standards. EPA 440/4-79/029b.
- Collins, H. H., Jr., and N. R. Boyajian. 1965. *Familiar Garden Birds of America*. New York: Harper & Row.
- Connors, J. J., and H. T. Shacklette. 1975. *Background Geochemistry of Some Rocks, Soils, Plants, and Vegetables in the Conterminous United States*. Professional Paper 574-F. U. S. Geological Survey.
- Cronin, K. L., and E. L. Bradley. 1988. The Relationship Between Food Intake, Body Fat, and Reproductive Inhibition in Prairie Deer Mice (*Peromyscus maniculatus bairdii*). *Comp. Biochem. Physiol. A. Comp. Physiol.* 89:669–673.
- Department of Health, State of Hawaii (DOH). 1990. *Aquifer Identification and Classification for Oahu*. Honolulu.

- . 1995a. *Determination of Groundwater Utility at Leaking Underground Storage Tank Sites*. Honolulu. September.
- . 1995b. *Reporting, Remediation, and Management of Petroleum-Contaminated Soil*. Honolulu. December.
- . 1995c. *Risk-Based Corrective Action and Decision Making at Sites with Contaminated Soil and Groundwater, Volumes I and II*. Honolulu. December.
- . 1996a. Addendum to Tier 1 look up tables in *Risk-Based Corrective Action and Decision Making at Sites with Contaminated Soil and Groundwater*. Honolulu. 24 February.
- . 1996b. *Example Re-Assessment of Groundwater Utility and Applicable Soil and Groundwater Action Levels*. Honolulu. 4 January.
- Department of Land and Natural Resources, State of Hawaii (DLNR). 1998. *State of Hawaii Groundwater Index and Summary*.
- Department of the Navy (DON). 1996. *Project Procedures Manual, U.S. Navy PACDIV Installation Restoration Program (IRP)*. Pearl Harbor, Hawaii: Pacific Division, Naval Facilities Engineering Command (PACNAVFACENGCOM).
- . 1997. *Navy/Marine Corps Installation Restoration Manual*. September.
- . 1998. *Project Procedures Manual, U.S. Navy PACDIV Installation Restoration Program (IRP)*. Pearl Harbor, Hawaii: PACNAVFACENGCOM.
- . 1999. *Navy Policy for Conducting Ecological Risk Assessments*. CNO Letter Ser. N453E/9U595355. Washington, D.C. 5 April.
- Dunning, J. B. 1993. *Body Weights of 686 Species of North American Birds*. Monograph No. 1. Suisun, Calif.: International Wildlife Rehabilitation Council. Reprinted from Western Bird Banding Association, May 1984.
- Earth Tech, Inc. 1998. *Revised Sampling and Analysis Plan for the Phase II Remedial Investigation, Ewa Junction Fuel Drumming Facility, Fleet and Industrial Supply Center, Pearl Harbor, Hawaii*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. Honolulu. July.
- Edens, F. W., and J. D. Garlich. 1983. Lead-Induced Egg Production Decrease in Leghorn and Japanese Quail Hens. *Poultry Science* 62:1757-1763.
- Environmental Protection Agency, United States (EPA). 1975. *Manual of Individual Water Supply Systems*.
- . 1985. *Exposure and Risk Assessment for Lead*. EPA/440/4-85/010.
- . 1988a. *CERCLA Compliance with Other Laws Manual: Interim Final*. EPA/540/G-89/006. August.
- . 1988b. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA*. Interim Final. EPA/540/G-89/004. October.

- . 1989a. *Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual (Part A)*. Interim Final. EPA/540/1-89/002. Office of Emergency and Remedial Response. December.
- . 1989b. *Risk Assessment Guidance for Superfund, Vol. II: Environmental Evaluation Manual*. Interim Final. EPA/540/1-89/001. March.
- . 1991. *Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual Supplemental Guidance: Standard Default Exposure Factors*. Office of Emergency and Remedial Response. March.
- . 1992. *Supplemental Guidance to RAGS: Calculating the Concentration Term*. Memorandum from Larry G. Reed, Director of Hazardous Waste Site Evaluation Division, Office of Emergency and Remedial Response, OERR. EPA/9285.7-081. 22 June.
- . 1993a. *Provisional Guidance for Quantitative Risk Assessment of Polycyclic Aromatic Hydrocarbons*. EPA/600/R-93/089. Office of Research and Development. July.
- . 1993b. *Wildlife Exposure Factors Handbook, Vol. I*. EPA/600/R-93/187a. Office of Research and Development. December.
- . 1994a. *Integrated Exposure Uptake Biokinetic Model for Lead in Children (IEUBK)*. PB94-501517. Office of Emergency and Remedial Response.
- . 1994b. *Laboratory Data Validation Functional Guidelines for Evaluating Inorganics Analysis*. EPA/540/R-94/083.
- . 1994c. *Laboratory Data Validation Functional Guidelines for Evaluating Organics Analysis*. EPA/540/R-94/082.
- . 1995. *Environmental Fate Constants for Additional 27 Organic Chemicals Under Consideration for EPA's Hazardous Waste Identification Projects*. EPA/600/SR-95/039.
- . 1997a. *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessment*. Interim Final. EPA/540/R-97/006. Office of Solid Waste and Emergency Response. June.
- . 1997b. *Exposure Factors Handbook, Vol. I: General Factors*. EPA/600/P-95/002Fa. Office of Research and Development. August.
- . 1997c. *Exposure Factors Handbook, Vol. II: Food Ingestion Factors*. EPA/600/P-95/002Fb. Office of Research and Development. August.
- . 1997d. *Health Effects Assessment Summary Tables (HEAST)*. Update. PB97-921199. Office of Solid Waste and Emergency Response. July.
- . 1997e. *Risk Assessment Guidance for Superfund, Vol. I: Human Health Evaluation Manual, Supplemental Guidance, Dermal Risk Assessment, Interim Guidance*. NCEA-W-0364. Office of Emergency and Remedial Response. December.
- . 1998. *BIOPLUME III Natural Attenuation Decision Support System, Users Manual, Version 1.0*. EPA/600/R-98/010. January.

- . 1999a. *Integrated Risk Information System (IRIS)*. On-line database of human health effects that may result from exposure to various substances found in the environment. URL: <http://www.epa.gov/iris/>.
- . 1999b. *National Recommended Water Quality Criteria*. Office of Water. URL: <http://www.epa.gov/OST/standards/wqcriteria.html>.
- Environmental Protection Agency, United States, Region IX (EPA Region IX). 1998. *Preliminary Remediation Goals*. May.
- Environmental Science and Engineering, Inc. (ESE). 1990. *Results of Underground Storage Tank Leak Detection Program for NSC Pearl Harbor*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. May.
- Freeze, R. A., and J. A. Cherry. 1979. *Groundwater*. Englewood Cliffs, N.J.: Prentice-Hall.
- Gilbert, R. O. 1987. *Statistical Methods for Environmental Pollution Monitoring*. New York: Van Nostrand Reinhold.
- Harding Lawson Associates (HLA). 1990. *Site Inspection, Ewa Junction MOGAS Spill, NSC, Pearl Harbor, Hawaii*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. 24 August.
- Hawaii State Data Center. 1991. *Data Book, A Statistical Abstract*. Honolulu: State of Hawaii, Department of Business, Economic Development, and Tourism.
- Heinz, G. H., D. J. Hoffman, and L. J. Gold. 1988. Toxicity of Organic and Inorganic Selenium to Mallard Ducklings. *Arch. Environ. Contam. Toxicol.* 17:561–568.
- Kampbell, D. H., J. T. Wilson, and S. A. Vandergrift. 1989. Dissolved Oxygen and Methane in Water by a GC Headspace Equilibration Technique. *Intern. J. Environ. Ana. Chem.* 36:249–257.
- Klaassen, C. D., and D. L. Eaton. 1991. Principles of toxicology. In *Casarett and Doull's Toxicology: The Basic Science of Poisons*, eds. M. O. Andur, J. Doull, and C. D. Klassen. 4th ed. New York: Permagon Press.
- Kreulen, D. A., and T. Jager. 1984. *The Significance of Soil Ingestion in the Utilization of Arid Rangelands by Large Herbivores, with Special Reference to Natural Licks on the Kalahari Pans*. International Symposium on Herbivore Nutrition in the Subtropics and Tropics. (1983: Pretoria, South Africa.) Draignall, South Africa: Science Press.
- Lyman, W. J., W. F. Rechl, and D. H. Rosenblatt (eds). 1982. *Handbook of Chemical Property Estimation Methods: Environmental Behavior of Organic Compounds*. New York: McGraw-Hill.
- Lauenstein, G. G., and Cantillo, A. Y. (eds.). 1993. *Sampling and Analytical Methods of the National Status and Trends Program National Benthic Surveillance and Mussel Watch Projects 1984–1992, Volume I, Overview and Summary of Methods*. NOAA Technical Memorandum NOS ORCA 71. Silver Spring, Md. July.
- Long, E. R., D. D. MacDonald, S. L. Smith, and F. D. Calder. 1995. Incidence of Adverse Biological Effects within Ranges of Chemical Concentrations in Marine and Estuarine Sediments. *Environmental Management* 19(1): 81–97.

- Mackay, D., W. Y. Shiu, and R. P. Sutherland. 1979. Determination of Air-Water Henry's Law Constants for Hydrophilic Pollutants. *Environmental Science and Technology* 13:333-337.
- Masa Fujioka & Associates (MFA). 1992. *Phase II Environmental Site Assessment, Ewa Junction Navy Drum Site, Areas 1, 2, & 4, TMK: 9-4-8: 10 and 9-6-3:44, Ewa Junction, Oahu, Hawaii*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. 21 April.
- Massachusetts Contingency Plan (MCP). 1995. *Guidance for Disposal Site Risk Characterization, Interim Final Policy*. WSC/ORS-95-141. Boston: Massachusetts Department of Environmental Protection.
- Mau, Francis K. Y. 1972. *Report of a Major Gasoline Spill at Pearl Harbor*. Pacific Division, Naval Facilities Engineering Command.
- Maybey, W. R., J. H. Smith, R. T. Podoll, H. L. Johnson, T. Mill, T. W. Chen, J. Gates, I. W. Partidge, H. Jaber, and D. Vandenburg. 1982. *Aquatic Fate Process Data for Organic Priority Pollutants*. EPA-440/4-81-014. Washington, D.C.: U.S. EPA Monitoring and Data Support Division, Office of Water Regulations and Standards.
- McDuffie, B., D. J. Russel, and J. J. Natishar. 1984. Potential for Migration in Groundwater. In *Proceedings of the Triangle Conference on Environment and Technology*. Durham, N.C.: Duke Univ.
- McKee, J. E., and H. W. Wolf. 1963. *Water Quality Criteria*. Publication 3-A (Reprinted July 1978). Sacramento: California State Water Resources Control Board.
- Mink, J. F. 1980. *State of the Ground Water Resources of Southern Oahu*. Honolulu: City and County of Honolulu.
- Mink, J. F., and L. S. Lau. 1990. *Aquifer Identification and Classification for Oahu: Groundwater Protection Strategy for Hawaii*. Rev. Technical Report no. 179. Honolulu: Univ. of Hawaii at Manoa, Water Resources Research Center.
- Mink, J. F., G. A. L. Yuen, and J. Y. C. Chang. 1988. *Review and Re-Evaluation of Groundwater Conditions in the Pearl Harbor Groundwater Control Area, Oahu, Hawaii*. State of Hawaii, Department of Land and Natural Resources, Board of Land and Natural Resources.
- National Library of Medicine. 1987. *Hazardous Substances Data Bank*. Specialized Information Services on-line database. Toxicology Data Network (TOXNET). <http://www.nlm.nih.gov/nlm/online/toxnet/>.
- National Research Council, Safe Drinking Water Committee (NRC Safe Drinking Water Committee). 1977. *Drinking Water and Health*. Vol. 1. Washington, D.C.: National Academy of Sciences.
- Naval Energy and Environmental Support Activity (NEESA). 1983. *Initial Assessment Study of Pearl Harbor Naval Base, Oahu, Hawaii: 13-002*. October.
- Nelson, A. L., and A. C. Martin. 1953. Gamebird Weights. *J. Wildl. Mgmt.* 17:36-42.
- Ogata, M., and Y. Miyake. 1978. Disappearance of Aromatic Hydrocarbons and Organic Sulfur Compounds from Fish Flesh Reared in Crude Oil Suspension. *Water Research* 12:1041-1044.

- Ogden Environmental and Energy Services Co. (Ogden). 1995. *Remedial Investigation Report for Pearl City Peninsula Landfill, PWC Pearl Harbor, Pearl City, Hawaii, Volume I – Technical Report*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. September.
- . 1996. *Remedial Investigation Report, Ewa Junction Fuel Drumming Facility, Fleet and Industrial Supply Center (FISC), Pearl Harbor, Hawaii*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. March.
- Okada Trucking Company (Okada). 1995. Letter to Mr. Leighton Wong, PACNAVFACENGCOM, Pearl Harbor, Hawaii, regarding: *Discovery of Soil Contamination at T.M.K. 9-6-03:37*. 30 August.
- Opresko, D. M., B. E. Sample, and G. W. Suter II. 1996. *Toxicological Benchmarks for Wildlife*. Revised. ES/ER/TM-86/R-2. Oak Ridge, Tenn.: Oak Ridge National Laboratory.
- Perry, T. D. 1984. Tree Roots: Facts and Fallacies. *Arnoldia* 49(4).
- PRC Environmental Management, Inc. (PRC). 1998. *Development of Toxicity Reference Values as Part of a Regional Approach for Conducting Ecological Risk Assessments at Naval Facilities in California*. Draft Technical Memorandum. Prepared for Department of the Navy, Engineering Field Activity West, Naval Facilities Engineering Command, San Bruno, California, under contract N62474-94-D-7609, CTO 027. San Francisco. July.
- Sample, B. E., J. J. Beauchamp, R. A. Efroymsen, G. W. Suter II, and T. L. Ashwood. 1998. *Development and Validation of Bioaccumulation Models for Earthworms*. ES/ER/TM-220. Oak Ridge, Tenn.: Oak Ridge National Laboratories, U.S. Department of Energy.
- Schlesinger, W. H., and G. L. Potter. 1974. Lead, Copper, and Cadmium Concentrations in Small Mammals in the Hubbard Brook Experimental Forest. *Oikos* 25:148–152.
- Schoener, T. 1968. Sizes of Feeding Territories among Birds. *Ecology* 49 (Cambridge, Mass.: Harvard Univ.).
- Smith, S. L., D. D. McDonald, K. A. Kleen, C. G. Ingersoll, and L. J. Field. 1996. A Preliminary Evaluation of Sediment Quality Assessment Values for Freshwater Ecosystems. *Journal of Great Lakes Research* 22(3): 624–638.
- Speitel, G. E., and F. B. Cloosmann. 1991. Chlorinated Solvent Biodegradation by Methanotrophs in Unsaturated Soils. *J. Environmental Engineering* 117:541–548.
- Stralka, D. 1995. EPA Region IX Toxicologist. Personal communication with Xuannga Mahini of Ogden Environmental and Energy Services, Inc. 30 August.
- Streng, D. L., and S. R. Peterson. 1989. Chemical Data Bases for the Multimedia Environmental Pollutant Assessment System (Mepas). Version 1. PNL-7145. Richland, Wash.: Pacific Northwest Laboratories.
- Sunn, Low, Tom, and Hara. (SLTH). 1975. *Final Report on the Investigation of Ewa Junction Fuel Storage Area March 1971 Fuel Spill*. Pearl Harbor, Hawaii: PACNAVFACENGCOM. June.
- Suter, G. W., II, and C. L. Tsao. 1996. *Toxicological Benchmarks for Screening Potential Contaminants of Concern for Effects on Aquatic Biota: 1996 Revision*. ES/ER/TM-96/R2.

- Prepared for Office of Environmental Management, U.S. Department of Energy. Prepared by Health Sciences Research Division, Oak Ridge National Laboratory Risk Assessment Program, Oak Ridge, Tenn.
- Travis, C. C., and A. D. Arms. 1988. Bioconcentration of Organics in Beef, Milk, and Vegetation. *Environ. Sci. Technol.* 22:271–274.
- United States Fish and Wildlife Service (USFWS). 1991. *Species in the State of Hawaii which are Listed or Proposed by the Federal Government as Endangered or Threatened*.
- Walton, W. C. 1988. *Practical Aspects of Ground Water Modeling*. Dublin, Ohio: National Water Well Association.
- Weidemeier, T. H., J. T. Wilson, D. H. Kampbell, R. N. Miller, and J. E. Hansen. 1995. *Technical Protocol for Implementing Intrinsic Remediation with Long-Term Monitoring for Natural Attenuation of Fuel Contamination Dissolved in Groundwater*. San Antonio, Tex.: Air Force Center for Environmental Excellence, Technology Transfer Division.
- Wentworth, C. K. 1951. *Geology and Groundwater Resources of the Honolulu-Pearl Harbor Area Oahu, Hawaii*. Honolulu: Board of Water Supply.
- Whitaker, J. O. 1966. Food of *Mus musculus*, *Peromyscus maniculatus bairdii*, and *Peromyscus leucopus* in Vigo County, Indiana. *J. Mammal.* 47:473–486.
- Wolff, J. O. 1985. The Effects of Density, Food, and Interspecific Interference on Home Range Size in *Peromyscus leucopus* and *Peromyscus maniculatus*. *Can. J. Zool.* 63:2657–2662.